~~CONFIDENTIAL~~

~~RESTRICTED~~

MINUTES AND PROCEEDINGS

of the twenty-second meeting of the

ARMED FORCES - NRC VISION COMMITTEE

November 11-12, 1948

School of Aviation Medicine
Air University
Randolph Air Force Base
Randolph Field, Texas

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C. 50: 31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~CONFIDENTIAL~~

~~RESTRICTED~~

[redacted]

ARMED FORCES-NRC VISION COMMITTEE

Chairman: Richard G. Scobee (M.D.)
Deputy Chairman: Col. Victor A. Byrnes (MC) USAF
Executive Secretary: Donald G. Marquis
Technical Aide: H. Richard Blackwell
Research Associate: William Berry

EXECUTIVE COMMITTEE

Official Members	Members at Large
T. G. Andrews	Conrad C. Berens
Detlev W. Bronk	Arthur C. Hardy
Victor A. Byrnes	E. O. Hulburt
C. W. Shilling	Richard G. Scobee

MEMBERSHIP AND DISTRIBUTION LIST

	MEMBERS	ALTERNATES
Air Force	Col. Ben C. Holzman HQ, USAF, DC/AS, Research & Development Room 3D1079, The Pentagon Washington 25, D. C.	Major William P. Mellon Air Weather Service Military Air Transport Service Washington, D. C.
	Col. Victor A. Byrnes, M.C. Air University School of Aviation Medicine Randolph Air Force Base Randolph Field, Texas	Dr. Paul M. Fitts Aero Medical Laboratory, MCREXD Psychology Branch Wright Field, Dayton, Ohio
ARMY AGF	Col. Walter J. Klepinger Washington Deputy, AGF Room 4C-761, The Pentagon Washington 25, D. C.	Lt. Col. E. E. Farnsworth Development Section Office, Chief, Army Field Force Fort Monroe, Virginia
AGO	Dr. Donald E. Baier Personnel Research & Procedures Branch Office of the Adjutant General The Pentagon, Washington, D. C.	Dr. Julius Uhlaner Personnel Research & Procedures Branch Office of the Adjutant General The Pentagon, Washington, D. C.
Engrs.	Mr. George E. Brown Engineer Research & Development Laboratories Corps of Engineers Fort Belvoir, Virginia	Mr. George W. Franks Engineer Research & Development Laboratories Corps of Engineers Fort Belvoir, Virginia
General Staff	Dr. T. G. Andrews Research & Development Group Logistics Division General Staff, U. S. Army Washington, D. C.	

[redacted]

	MEMBERS	ALTERNATES
Ord.	Mr. John E. Darr, Jr. Ordnance Research & Development Div. Room 4C-430, The Pentagon Washington, 25, D. C.	Dr. William S. Carlson Fire Control Division Frankford Arsenal Philadelphia 37, Pa.
P&A Div. GSUSA	Major J. Paul Bertrand Classification and Standards Branch Personnel & Administration Div., GSUSA Washington, D. C.	
QMG	Col. Jack E. Finks Chief, Research & Development Branch Office of the QM General Washington 25, D. C.	Mr. John Rich Research & Development Branch Office of the QM General Washington 25, D. C.
Signal Corps	Mr. Normand Stulman Special Projects Branch Engineer & Technical Service Office, Chief Signal Officer Room 3C-278, The Pentagon Washington, D. C.	Mr. T. E. Hedman Special Projects Branch Engineer & Technical Service Office, Chief Signal Officer Room 3C-278, The Pentagon Washington, D. C.
SG	Col. Austin Lowery Jr. (MC) Officer in Charge, Eye Clinic Walter Reed General Hospital Army Medical Center Washington 12, D. C.	Lt. Col. Charles S. Gersoni, MSC Neuropsychiatry Consultante Division Office of the Surgeon General Washington, D. C.
NAVY BuAer	Comdr. H. W. Crews Bureau of Aeronautics, Navy Dept. Washington, D. C.	Mr. Leslie C. Mackrill Airborne Equipment Division Navigation Branch Room 1W53, BuAer, Navy Dept. Washington 25, D. C.
BuMed	Comdr. Harold Smedal Bureau of Medicine & Surgery Navy Dept. Washington 25, D. C.	
BuOrd	Mr. Michael Goldberg Bureau of Ordnance Navy Department Washington 25, D. C.	
BuPers	Captain E. W. Herron, USN Bureau of Naval Personnel Navy Department Washington 25, D. C.	Dr. Everett G. Brundage Bureau of Naval Personnel Navy Department Washington 25, D. C.
BuShips	Comdr. Dayton R. E. Brown Bureau of Ships Code 631, Navy Department Washington 25, D. C.	Captain H. T. Chase, Code 624 Bureau of Ships Navy Department Washington 25, D. C.

	MEMBERS	ALTERNATES
	Mr. C. S. Woodside Bureau of Ships, Section 921 Navy Department, Washington, D. C.	Mr. L. Nelson, Code 947, Room 3350 Bureau of Ships Navy Department, Washington, D. C.
NavOrd Test Sta.	Dr. Roger S. Estey U. S. Naval Ordnance Test Station Inyokern, California	Mr. Theodore Whitney U. S. Naval Ordnance Test Station Inyokern, California
NRL	Dr. E. O. Hulburt Naval Research Laboratory Anacostia, Washington, D. C.	Dr. Richard Tousey Naval Research Laboratory Anacostia, Washington, D. C.
ONR	Captain C. W. Shilling Director, Medical Sciences Division Office of Naval Research Navy Department, Washington, D. C.	Dr. Henry A. Imus Head, Psychophysiology Branch Medical Sciences Division Office of Naval Research Navy Department, Washington, D. C.
Marine Corps	Major Walter L. Eddy, Jr. Room 2130, Division P & P Headquarters, USMC Washington 25, D. C.	

NATIONAL RESEARCH COUNCIL MEMBERS

Dr. Stanley S. Ballard Head, Department of Physics Tufts College Medford, Massachusetts	Dr. Conrad Berens Ophthalmological Foundation, Inc. 301 East Fourteenth St. New York, N. Y.
Dr. Detlev W. Bronk Johnson Foundation for Med. Physics School of Medicine University of Pennsylvania Philadelphia, Pennsylvania	Dr. George M. Byram Southeastern Forest Experiment Sta. Federal Building Asheville, North Carolina
Dr. Theodore Dunham Harvard Medical School 25 Shattuck Street Boston 15, Massachusetts	Dr. S. Q. Duntley Room 4-306 Massachusetts Inst. of Technology Cambridge, Massachusetts
Dr. Glen A. Fry Director, School of Optometry The Ohio State University Columbus 10, Ohio	Dr. J. J. Gibson Dept. of Psychology Smith College Northampton, Massachusetts
Dr. Frank Geldard Dept. of Psychology University of Virginia Peabody Hall Charlottesville, Va.	Dr. Clarence H. Graham Dept. of Psychology Columbia University New York, New York

Dr. Arthur C. Hardy
Department of Physics
Massachusetts Inst. of Technology
Cambridge 39, Massachusetts

Dr. Walter Miles
Yale School of Medicine
New Haven, Connecticut

Dr. Kenneth Ogle
Division of Physics & Biophysical Res.
Mayo Clinic
Rochester, Minnesota

Dr. Louise Sloan
Wilmer Ophthalmological Institute
The Johns Hopkins School of Medicine
Baltimore, Maryland

Dr. George Wald
Biological Laboratories
Harvard University
Cambridge, Massachusetts

Dr. H. K. Hartline
Johnson Foundation for Med. Physics
School of Medicine, University of Pa
Philadelphia, Pennsylvania

Dr. Brian O'Brien
Director, Institute of Optics
University of Rochester
Rochester 7, New York

Dr. Richard G. Scobee
Department of Ophthalmology
Washington University
St. Louis, Missouri

Dr. Morris S. Viteles
Department of Psychology
106 College Hall
University of Pennsylvania
Philadelphia, Pennsylvania

LIAISON MEMBERS

U. S. Coast Guard
Commander R. T. Alexander
Chief, Testing & Development Div.
Coast Guard Headquarters
Washington, D. C.

Illuminating Engineering Society
Mr. C. L. Crouch
Illuminating Engineering Society
51 Madison Avenue
New York, New York

Inter-Society Color Council
Dr. Deane B. Judd
National Bureau of Standards
Washington, D. C.

National Bureau of Standards
Mr. C. A. Douglas
National Bureau of Standards
Washington, D. C.

Civil Aeronautics Administration
Dr. Barry G. King
Aviation Medical Service
Civil Aeronautics Admin.,
Washington, D. C.

ASSOCIATE MEMBERS

Dr. Neil R. Bartlett
Psychology Dept.
Hobart College
Geneva, New York

Dr. Lloyd H. Beck
Department of Psychology
Yale University
New Haven, Connecticut

Dr. S. Howard Bartley
Department of Psychology
Michigan State College
East Lansing, Michigan

Mr. E. Boghosian
Bureau of Ships, Code 660
Navy Department
Washington, D. C.

Dr. F. S. Brackett
Industrial Hygiene Research Lab.
National Institute of Health
Bethesda, Maryland

Dr. Alphonse Chapanis
Systems Research Project
Johns Hopkins University
Baltimore 18, Maryland

Dr. Forrest L. Dimmick
Medical Research Department
U. S. Submarine Base
New London, Connecticut

Lt. Comdr. Dean Farnsworth
Medical Research Department
U. S. Submarine Base
New London, Connecticut

Dr. David Freeman
Dept. of Ophthalmology
Washington University
St. Louis, Missouri

Dr. K. S. Gibson
National Bureau of Standard
Washington 25, D. C.

Dr. Walter Grether
Aero Medical Laboratory, MCREXD
Psychology Branch
Wright Field, Dayton, Ohio

Mr. Louis P. Harrison
Chief, Technical Investigation Sec.
U. S. Weather Bureau
Washington, D. C.

Mr. Lawrence Karlin
AGO, Room 12878, Dept. of the Army
The Pentagon, Washington, D. C.

Mrs. Elizabeth Kelly
Physics Branch, ONR
Navy Department
Washington, D. C.

Dr. E. S. Lamar
Operations Evaluation Group
Navy Department
Washington 25, D. C.

Mr. F. C. Breckenridge
National Bureau of Standards
Washington, D. C.

Dr. Howard S. Coleman
Dept. of Physics
University of Texas
Austin, Texas

Lt. Comdr. Ellsworth B. Cook
Medical Research Department
U. S. Submarine Base
New London, Connecticut

Mr. W. C. Fisher
Electronics Division, EL-63
Bureau of Aeronautics
Navy Department
Washington, D. C.

Dr. Irvine C. Gardner
National Bureau of Standards
Washington 25, D. C.

Dr. Earl Green
Department of Zoology
The Ohio State University
Columbus 10, Ohio

Dr. LeGrand Hardy
Institute of Ophthalmology
The Presbyterian Hospital
635 West 165th Street
New York 32, New York

Dr. E. Parker Johnson
Bowdoin College
Brunswick, Maine

Mr. Harry J. Keegan
Division of Photometry & Colorimetry
National Bureau of Standards
Washington, D. C.

Dr. John L. Kennedy
Research Lab. of Sensory Psychology and Physiology
Tufts College, Medford, Massachusetts

Commander R. H. Lee
Naval Medical Research Institute
Bethesda, Maryland

Dr. Urner Liddel
Office of Naval Research,
Navy Department
Washington, D. C.

Dr. Leonard C. Mead
Department of Psychology
Tufts College
Medford, Massachusetts

Dr. Conrad G. Mueller
Department of Psychology
Columbia University
New York, New York

Lt. Harry Older
Aviation Psychology Branch
Bureau of Medicine and Surgery
Navy Department, Washington, D. C.

Mr. Nathan Pulling
Biological Laboratories
Harvard University
Cambridge, Massachusetts

Dr. Gertrude Rand
The Institute of Ophthalmology
The Presbyterian Hospital
635 West 165th St., New York, N. Y.

Professor Sherman Ross
Dept. of Psychology
Bucknell University
Lewisburg, Pennsylvania

Dr. William Rowland
Wilmer Ophthalmological Institute
The Johns Hopkins School of Medicine
Baltimore, Maryland

Dr. Charles Sheard
Div. of Physics & Biophysical Research
Mayo Foundation
Rochester, Minnesota

Capt. J. T. Smith (MC) USN
School of Aviation Medicine
Pensacola, Florida

Dr. Jacinto Steinhardt
Operations Evaluation Group
Room 3827, Navy Dept.
Washington 25, D. C.

Mr. A. Lovoff
Section 947A
Bureau of Ships, Navy Dept.
Washington, D. C.

Dr. Carl Miller
Department of Physics
Brown University
Providence, Rhode Island

Dr. Hans Neuberger
Chief, Division of Meteorology
Pennsylvania State College
State College, Pennsylvania

Dr. James C. Peskin
Vision Research Laboratory
304 West Medical Bldg., U. of M.
Ann Arbor, Michigan

Lt. George W. Rand (MC) USN
School of Aviation Medicine
Pensacola, Florida

Dr. Lorrin A. Riggs
Dept. of Psychology
Brown University
Providence, Rhode Island

Major Lee Rostenberg
426 Port Road
Port Chester, New York

Dr. Clifford P. Seitz
Flight Section
Special Devices Center
Sands Point, Long Island, N. Y.

Mr. W. R. Sidle
Instruments Branch, AE-72
BuAer, Navy Dept.
Washington, D. C.

Dr. John Sulzman
1831 Fifth Avenue
Troy, New York

Dr. Joseph C. Tiffin
Dept. of Psychology
Purdue University
Lafayette, Indiana

Dr. W. S. Verplanck
Dept. of Psychology
Indiana University
Bloomington, Indiana

Dr. Herman S. Wigodsky
Committee on Atomic Casualties
National Research Council
Washington 25, D. C.

Dr. Robert Wherry
Dept. of Psychology
Ohio State University
Columbus 10, Ohio

Dr. Benjamin J. Wolpaw
2323 Prospect Avenue
Cleveland, Ohio

ADDITIONAL DISTRIBUTION

Surgeon Captain R. A. Graff
British Medical Liaison Officer
Building 4, Room 60A
23rd and Streets
Washington, D. C.

Captain Wilbur E. Kellum (MC)
School of Aviation Medicine
Naval Air Station
Pensacola, Florida

Wing Commander J. H. Neal
British Joint Services Mission
1785 Massachusetts Avenue, N.W.
Washington, D. C.

Mr. W. K. Middleton
Physics Section
National Research Council
Ottawa, Canada

Dr. Arnold M. Small
Psychological Consultant
U. S. Navy Electronics Lab.
San Diego 52, California

Aero Medical Equipment Laboratory
Naval Air Experimental Station
Navy Air Material Center
Philadelphia 12, Pennsylvania

Captain Thomas L. Willmon
Medical Research Dept.
U. S. Submarine Base
New London, Connecticut

Captain R. C. Young
Office of Naval Research
Navy Department
844 North Rush Street
Chicago, Illinois

Dr. William E. Kappauf
Dept. of Psychology
Princeton University
Princeton, New Jersey

Dr. John Lentz
Secretary, NRC Committee on Ophthalmalogy
National Research Council
Washington, D. C.

Dr. Duncan Macdonald
Optical Research Laboratory
Boston University
Boston, Massachusetts

Dr. T. W. Reece
Director, Psychophysical Reasearch Unit
Dept. of Psychology & Education
Mount Holyoke College
South Hadley, Massachusetts

Lt. Comdr. G. F. Vance, USN
Optics Section Re40
Bureau of Ordnance
Navy Dept., Washington 25, D. C.

Mr. M. O. Watson· Air Attache
Scientific Research Liaison Office
Australian Legation
Washington, D. C.

Dr. F. N. Woodward
Director, United Kingdom Scientific Mission
1785 Massachusetts Avenue, N.W.
Washington 6, D. C.

Army Field Forces Board No. 1
Fort Bragg, North Carolina

Army Ground Forces Board No 4
Ft. Bliss, Texas

Director, Research Activity
Bureau of Personnel
Navy Department
Washington, D. C.

Director, System Research Project
Johns Hopkins University
Baltimore 18, Maryland

Training Library
Bureau of Naval Personnel
Navy Dept., Washington, D. C.

Aviation Psychology Branch
Air Medical Section
Headquarters Strategic Air Command
Andrews Field, Washington 20, D. C.

Lt. Col. Anthony Tucker
Office of the Air Surgeon
Washington, D. C.

Department of the Army
Army Medical Library
Washington 25, D. C.
Att: Mr. Scott Adams

Army Ground Forces Board No. 2
Fort Knox, Kentucky

Director of Research
AAF School of Aviation Medicine
Randolph Field, Texas

Naval Medical Field Research Lab.
Camp Lejeune
New River, North Carolina

Office of the Naval Attache
20 Grosvener Square
London W1, England
Att: Medical Representative

Chief, Bureau of Medicine & Surgery
Att: Div. of Aviation Medicine
Navy Dept., Potomac Annex
Washington 25, D. C.

Chief, Science & Technology Project
The Library of Congress
Washington 25, D. C.
Att: Mrs. H. L. Conn

Librarian of Medical Records
Division of Medical Sciences
National Research Council
2101 Constitution Ave., Washington, D.C

NRC COMMITTEE ON OPHTHALMOLOGY

Dr. Alan C. Woods
The Johns Hopkins Hospital
Baltimore 5, Maryland

Dr. Edwin B. Dunphy
243 Charles Street
Boston 14, Mass.

Dr. Trygve Gundersen
101 Bay State Road
Boston 15, Mass.

Dr. Lawrence T. Post
508 N. Grand Blvd.
St. Louis 3, Mo.

Dr. Algernon B. Reese
73 East 71st Street
New York 21, N. Y.

Dr. Derrick T. Vail
Northwestern University
Medical School
303 East Chicago Avenue
Chicago 11, Illinois

ARMED FORCES-NRC VISION COMMITTEE

Minutes of the Twenty-second Meeting

November 11-12, 1948

School of Aviation Medicine
Air University
Randolph Air Force Base
Randolph Field, Texas

The following were present:

AIR FORCES		(M) Colonel Victor A. Byrnes (A) William P. Mellon
	SAM Randolph Field	Dr. K. Buettner Dr. J. L. Matthews Lt. P. H. Ripple Dr. H. W. Rose Dr. Ingeborg Schmidt Dr. S. B. Sells Captain John J. Suits
ARMY	AGO	(M) Dr. Julius Uhlaner
	General Staff	(M) Dr. T. G. Andrews
	Ordnance	(M) Mr. John E. Darr, Jr.
	SG	(M) Colonel Austin Lowery Jr. (MC)
NAVY	BuMed	(M) Commander Harold Smedal
	BuShips	(M) Commander Dayton R. E. Brown
	NRL	(M) Dr. E. O. Hulburt (A) Dr. Richard Tousey
	ONR	(M) Captain C. W. Shilling (A) Dr. Henry A. Imus Mr. Frank B. Isakson Lt. Commander C. F. Vance
	Sub Base New London	Lt. Commander E. B. Cook Dr. Forrest L. Dimmick Lt. Commander Dean Farnsworth
NRC MEMBERS		Dr. Conrad Berens Dr. S. Q. Duntley Dr. Kenneth Ogle Dr. Richard Scobee Dr. Louise Sloan

LIAISON MEMBERS

Commander R. T. Alexander, U. S. Coast Guard
Mr. C. A. Douglas, National Bureau of Standards

ASSOCIATE MEMBERS

Mr. F. C. Breckenridge
Dr. Howard S. Coleman
Dr. David Freeman
Lt. George W. Rand
Dr. William Rowland
Captain J. T. Smith
Dr. Walter Grether

GUESTS

Miss Irene Blasdel, Naval Aviation Experiment Station, Philadelphia
Dr. William Berry, Vision Committee Secretariat
Mrs. Josephine J. Brennan, Eng. Research & Develo- ment Laboratory, Ft. Belvoir, Virginia
Colonel D. B. Dill, Chevy Chase, Maryland (Med. Div. of Army)
Dr. F. G. Hall, Duke University
Mr. Adolph H. Humphreys, Ft. Belvoir, Virginia
Colonel A. L. Jennings, MacDill Air Force Base, Tampa, Florida
Colonel W. J. Kennard, Office of the Air Surgeon
Dr. Hedwig S. Kuhn, Kuhn Clinic, Hammond, Indian
Dr. Donald G. Marquis, Vision Committee Secretari
Major Robert A. Patterson, Air Surgeon's Office
Colonel A. H. Schwichtenberg (MC), Hq. USAF-SGO
Commander K. S. Scott, Naval Aviation Experiment Station, Philadelphia
Colonel R. K. Simpson, Kerriville, Texas
Colonel L. H. Thorne, San Antonio, Texas

Thursday Morning, December 11, 1948 Page No.

1. Dr. Richard G. Scobee, Chairman, called the meeting to order.

2. The Chairman called for corrections or additions to the Minutes & Proceedings of the 21st meeting. The following omission in the Minutes and Proceedings of the May 26, 1948 meeting of the Subcommittee on Visual Standards, included in the Minutes and Proceedings of the 21st meeting of the Vision Committee, is recorded:

   "It is recommended that no time should be taken up by a study of the keystone Telebinocular, and that it should not be considered until certain initial items including the illumination and the manipulation of the test targets are standardized."

3. Colonel Victor A. Byrnes welcomed the Vision Committee to Randolph Field on behalf of Brigadier General Armstrong.

4. Dr. Siegfried Gerathewohl presented a paper entitled "A Study on the Efficiency of Aircraft Insignia". The text of his report is contained in the Proceedings - 15

5. Dr. John L. Matthews presented a paper entitled "The Effect of Ophthalmic Filters on Color Vision" - 21

6. Dr. Heinz Haber presented a paper entitled "Runway Markings and Identification Lighting" - 29

7. Dr. Hubertus Strughold presented a paper entitled "The Two Sides of The Physiological Effect of Intermittent Light" - 47

8. Dr. Werner Noell presented a paper entitled "Anoxic Effects on the Optic Pathway" - 53

9. Dr. Conrad Berens and Dr. S. B. Sells presented a paper concerned with Studies on Fatigue of Accommodation Using the Ophthalmic Ergograph - - - - - - - - - - - 59

10. The Chairman requested that the Minutes and Proceedings of the meeting of the Subcommittee on Visual Standards, held September 20, 1948, in Washington, D. C., be recorded. The report is included in the Proceedings - - - - - - - - - 87

11. Dr. David Freeman reported for Dr. Scobee on the meeting of the Subcommittee on Visual Standards. The report is found in the Proceedings - - - - - - - - - - 107

12. As a result of the work of the Subcommittee on Visual Standards, the following recommendations were approved by the Vision Committee:

RECOMMENDED THAT: The Service undertake a comprehensive analysis of the visual skills required for various specialized military tasks, together with adequate measures of proficiency in such tasks.

RECOMMENDED THAT: Regardless of present usage, the symbols V.R., V.L., and V.B., or the terms Right, Left, and Both, be used to designate vision in the right eye, vision in the left eye, and vision in both eyes, respectively, in connection with visual testing in the Armed Services.

RECOMMENDED THAT: (1) The Subcommittee does not believe that mass testing of night vision is at present necessary.

(2) Any interest in night vision should be centered around night vision training rather than testing.

(3) Further study of night vision tests is desirable and should be undertaken.

RECOMMENDED THAT: In view of the fact that PRS 742 from the Adjutant General's office revealed the absence of significant differences in test-retest reliability between the present Army Snellen and other available tests, the use of the Army Snellen test be continued with the following provisos: (1) Provision must be made for adequate manufacturing tolerances; (2) Great emphasis must be placed on proper testing technique, as outlined in the Vision Committee Manual for Testing Visual Acuity.

The AGO study revealed that several separable visual acuity factors exist which may be included or excluded by the selection of various acuity tests. Analysis of these factors can and should be the basis for further studies toward the goal of developing more ideal visual acuity tests. When the comprehensive analysis of visual skills required for specialized military tasks, recommended by the Vision Committee has been completed, appropriate visual acuity tests can perhaps be developed. Since it is recognized that the latter will take an indefinite period, the first recommendation contained herein is suggested for the moment in the light of, and with limitations of, present knowledge.

RECOMMENDED THAT: Because there is at present no conclusive evidence that tests of depth perception have high correlations with ability to fly aircraft, if the testing of depth perception is deemed desirable by the Services, in connection with the selection of flying personnel, in the opinion of the Subcommittee the Verhoeff Stereopter is as suitable as any other test available.

13. Dr. Heinz Haber presented a paper entitled "Color Saturation Threshold Meter"-- 113

14. Dr. Ingeborg Schmidt presented a paper entitled "Effect of Various Factors on Color Saturation Thresholds"------------------------ 117

Friday, November 12, 1948

15. Dr. H. W. Rose presented a paper entitled "Motion Parallax as a Factor of Depth Perception"-- 121

16. Tours of the Laboratories of the School of Aviation Medicine were arranged.

17. An air demonstration was presented, including the following: Jet fighter demonstration; Air-Sea rescue demonstration; Helicopter demonstration.

Page No.

A STUDY ON THE EFFICIENCY OF AIRCRAFT INSIGNIA

By
S. Gerathewohl, Ph. D.,
and
Heinz Haber, Ph. D.

The aim of our studies was the selection of aircraft insignia which would best meet the requirements of such a symbol of identification. The investigations carried out at the School of Aviation Medicine covered a period of about 11 months. Taking the individual phases of the test series as a whole we obtained from the test subjects more than 20,000 statements. The question may be raised whether the solution of such an apparently simple problem actually requires such effort. It is a fact, however, that this problem represents a complicated network of physiological, psychological and physical factors. Therefore, we had to divide the problem into its various component factors and investigate them separately. Because of the short time available, a detailed description of the experiments of their set-up and numerical evaluation cannot be given. An exhaustive report on our pertinent studies and their results will soon be published. But I am sure you will be interested in an abstract of our work, which, with the exception of the result of only one test series, has been completed.

Under efficiency of aircraft insignia we consider their optimum of perceptibility, visibility, and discernibility. By placing these three concepts side by side, the complex nature of our studies becomes obvious. Indeed, the set up of our experiments was based on these three concepts. It is for this reason that I am going to define them individually as they will be used.

1. An object is "perceptible" if the "minimum perceptible" is attained, i.e., when at least a point-like image of the object appears on the retina. This general definition, however, must be supplemented further; for we also speak of an object as "perceived" if, in general, the lowest stimulation threshold of the visual organ is stimulated.

2. An object is "visible" when it is seen and recognized. The visual threshold necessary for this process is called the "minimum visible" or the "minimum separabile generalis". This concept involves further conditions of physical, physiological and psychological nature, which exceed the usual prerequisites for the process of perception.

3. An object is "discernible" when we are able to draw a definite conclusion as to its identity. This requires that essential constituents of the object concerned are discernible, i.e., the "minimum separabile specificum" must be attained.

These three processes involve likewise three steps of psychological apprehension, which to an increasing degree demand a higher intellectual process.

The purpose of an aircraft insignia is to provide a quick and reliable identification by the observer. The preceding definitions have made it clear that beyond the stages of perception and vision, we must also fulfil the requirements of discernment and identification. Therefore, such an identification has comparatively high demands on the visual process and on its intellectual evaluation. Thus, the entire problem gains a specific psychological significance. First of all, we have to deal here with the apprehension of form and color elements as well as with the recognition

of configurations and color combinations. Therefore, our aim was to reduce as much as possible the "minimum separabile specificum" by a suitable selection of colors and forms. This minimum, in turn, represents a function of various physiological and psychological factors.

The color is distinguished by the specific quality inherent in it, which we may call "attractiveness" or "conspicuity". Therefore, colors are very well suited to serve as a stimulus for perception, vision, and identification. By conspicuity we mean here the characteristic quality of a color to attract the attention of the observer and to induce him to shift instinctively the stimulus to the spot of clearest vision. For this reason it was necessary to make studies on the order of conspicuity of the basic colors. Furthermore, we had to investigate the nature of the individual colors and color combinations under limited visual conditions, such as insufficient illumination and loss of contrast because of haze and fog.

For the investigation on the conspicuity of colors we had lantern slides made, of which each had ten colored discs on black or white background, arranged in apparently irregular order. During the test consisting of 432 short-time exposures, various arrangements of the colored dots were shown so that each color appeared an equal number of times at the same place (See Fig. 1). The test subjects were required to state the number and color of dots perceived. Thus, for the apprehension of each color we had the same conditions of exposure as to time and location. We can, therefore, draw the conclusion, that the degree of conspicuity of a color is proportional to the number of times it was noted by the test subjects.

Before continuing our investigations on the limited visual conditions we had to make a study on the number of colors to be used for the insignia, because in this case the phenomenon of contrast was involved. The use of only one color would reduce the contrast phenomenon and necessarily make the structural elements of the form fall short. The use of three colors would likewise reduce the contrast effect. Moreover, as a consequence thereof, the structural element would become more complicated, which in turn would reduce the degree of discernibility. For this reason our further investigations were carried out with combinations of two contrasting colors, which necessarily involve a certain element of form. This element was kept constant for the color test, namely, in the form of standard targets consisting of squares with the color "a" (length of a side 21 mm.) which were divided in the middle by a cross bar of a width of 7 mm. with the color "b". As test colors we used red, (Munsell Standard 5/16 for yellowish-red), yellow (reddish-yellow 8/10), green (yellowish-green 6/6 - bluish green 6/6), blue (bluish-purple blue 4/10 - purplish purple blue 2/12), and black and white.

The next step of our test series was the study of the effect of reduced brightness on the recognition of combinations consisting of two pigment colors. Twenty of the aforementioned targets were presented at illuminations whose brightness began at zero and increased gradually. The thresholds of recognizing the position of the cross bar in the middle and the color combination were individually determined. In this test series the targets were shown in four different positions. The determination of the threshold of recognizing the position of the target was supposed to determine the subjective difference in the brightness of the two colors. This determination concerned rod vision only. In the evaluation both threshold values were considered equally important for our purpose. They were used for establishing quantitative rating for the discernibility of the color combinations.

The third experiment with color combinations dealt with visibility impaired by haze and fog. For this experiment we used the fog simulator which Dr. Haber has described in his preceding lecture. The thresholds for recognizing position and color combination through the ground glass screen were determined and used as a basis for the rating of respective color combinations.

The final result of the three test series mentioned concerning conspicuity, low illumination, and ground glass screen, are compiled in tables. (See Fig.2). Altogether we had obtained five different series, which, numerically, were so reduced that the sum of each of the five score-groups amounted to 20 arbitrary units. High efficiency is indicated in all cases by a low score. The color combinations as shown in this table are classified in the sequence of efficiency by results obtained in our test series. The combination black-yellow ranks foremost, closely followed by the combination black-white. Whereas the combination blue-red seems the least suitable for our purpose.

Most aircraft insignia used in international aviation consist of varying geometric patterns. The colors as well as the design depend to a large extent on the traditions of the nations. It is for this reason that we cannot expect such insignia to meet our requirements outlined above. Our investigations, however, are based on unprejudiced considerations insofar as nationality and tradition are concerned. Therefore, the colors black-yellow were used for further experiments concerning form and shape of the test objects.

In the first phase of these experiments we used altogether 64 different insignia. Their designs were based on the simplest geometric patterns such as circles, squares, rectangles, triangles and possible combinations of these. In addition, we had the configuration of the cross and star with their manifold derivations and the Air Forces symbol of wings. Figure 3 shows a selection of the 64 insignia used in our tests. All insignia were of equal area; only the proportions of black and yellow varied systematically. We considered the threshold of resolvability of the individual insignia with ever increasing size of image on the retina as the most important criterion. In order to determine this threshold the insignia was brought closer and closer to the observer until he could correctly identify the symbol. The brightness was kept constant. In order to bridge too great distances, and to get the optimal visual condition necessary for this experiment, we used a reversed telescope, which diminished the measuring distance to 6 ft. During the slow approach of a certain insignia the observer passed in successive order through the three stages, previously mentioned, namely, those of perceptibility, visibility and discernibility. The threshold values characteristic for the individual insignia were scattered over this range. The statements of the test subjects during the experiment were psychologically very interesting, because of optical illusions and subjective deceptions. The psychological factor in the process of perception and, particularly that of the identification itself, became quite evident.

Figure 4 shows the 17 best insignia as a result of this first test series.

A further criterion for the value of an insignia is the degree with which the specific character of its pattern is recognized. In this case, attractiveness, impressibility and symbolism are decisive qualities. In our second test series, we, therefore, included more psychological factors beyond the purely physiological ones as, for instance, the resolving power and acuity of the eye. The tachistoscopic method seemed to be best suited for this purpose. In this instance the insignia were presented from such a distance and with such brightness that at prolonged exposure an accurate identification was always possible.

The 17 insignia were shown from two different distances with five different exposure times (1, 1/2, 1/5, 1/25, and 1/100 sec.). By statistical evaluation of the correct statements a rating for the discernibility of these badges at short exposures was derived.

In view of the final purpose of this investigation it was necessary to add another test; dealing with the influence of motion on the visibility of aircraft insignia. It is evident that this influence is considerable because the subjective clearness of the image decreases perceptibly above an angular velocity of 20° per sec. With still higher velocities, the object changes its shape and, finally, it is seen as a line or band. In this case, we find an equalization of the brightness difference of the adjacent fields within the object. This produces a blurr effect on those structural elements of the pattern which are arranged vertically to the direction of movement. On the other hand those elements which run parallel to the movement are still resolvable even at very high angular velocities.

In order to determine these phenomena quantitatively we subjected the 11 best insignia to a motion experiment. We had 11 color diapositives made which, by means of a projector mounted on a revolving stage, were projected on a concave screen. A ridgeless gear connected to the revolving stage permitted a continual reduction of the angular velocity from 360° per sec. to about 20° per sec. All insignia could easily and accurately be identified with the latter velocity. Symmetrical symbols were presented in only one position; square and rectangular symbols were shown in two perpendicular positions, and the only triangle of the group was projected in three different positions. The threshold of recognition of the individual insignia was determined by gradually decreasing the angular velocity. By this method we obtained the relative rating of the insignia with regard to their discernibility in translatory motion.

Similar to the color experiments we numerically reduced the three series so that the total of each of the three score groups amounted to 33.33 arbitrary units. This means, that the results of three experiments arbitrarily were rated equal.

Figure 5 demonstrates the results of our three test series. This result is shown although it is not quite complete. At present we are investigating, by means of the ground glass screen, the effect of contrast loss and blurring on the faculty of form perception. The results of this experiment may eventually change the present order to some extent. Therefore, the results shown must be considered as preliminary.

We believe that our preceding investigations have shed light on some basic problems of identification markings. In short, an uncomplicated design with the colors black and yellow will best meet all requirements of visual perception. The majority of all aircraft insignia presently used do not possess these properties so far as pattern and color are concerned. Our preceding results form a basis for the next step of our project. Our final aim is the development of a suitable aircraft insignia which in practical use fulfills all demands for easy identification.

When we take the high speeds of modern aircraft into consideration, there is a question of whether or not aircraft insignia of the present type have any value. We believe it will be necessary to replace the traditional symbols by distinctive markings which cover larger areas of the plane's surfaces. The results of our investigations also prove a sound basis for the development of markings of this kind.

DISCUSSION

Commander Brown asked whether any attemp had been made to analyze the data in terms of the separable effects of chromatic and achromatic contrast of the insignia. He expressed his belief that it was absolutely necessary to make this distinction if the data were to be understandable in terms of previously established information.

Commander Brown also mentioned that along with the requirement that the aircraft insignia provide adequate recognition, the insignia should not increase the basic detectability of the aircraft. He expressed his belief that this aspect of the insignia patterms could well have been investigated.

Dr. Haber stated that the Air Forces had not expressed interest in the low detectability aspect of insignia, and that therefore no attention had been given to this matter.

Dr. Blackwell referred to the studies conducted during the war by the NDRC Camouflage Section, particularly to the data on chromatic contrasts collected by Dr. McAdam. He suggested that the study conducted by Haber and Gerathewohl might have very profitably been tied in with the NDRC studies so that it would become increasingly possible for specific problems to be solved on the basis of general information available. Dr. Blackwell suggested that perhaps the data could be analyzed in terms of the NDRC studies even though the studies had not been used in setting up the experiment. He criticized the use of 5 degree angular subtense for the color discrimination portion of the experiment, in view of the fact that subsequent portions of the experiment utilized the colors at extremely small subtense. He referred to recent studies indicating the change in color thresholds at small substense. In addition, Dr. Blackwell stated his belief that color discrimination threshold data depend upon the frame of discrimination references given the observer. He asked whether the use of the color discrimination data, obtained under conditions of carefully specified possible color values, might not need some modification before being applied to the Service situation in which a less limited range of colors might be expected.

Dr. Grether questioned the validity of the "motion test" in which subjects were allowed to follow a target over a 60 degree field. Dr. Grether suggested that under normal circumstances, fixation of targets in pursuit is perfect so that blurredness of the stimulus does not exist.

Dr. Haber expressed his belief that fixation of moving targets was not as complete as Dr. Grether believed.

Dr. Dimmick reported that the use of yellow and black for high recognition is at least 20 years old, being used extensively in the design of license plates. He expressed surprise that aircraft insignia designers had never made use of this apparently well-established principle.

Dr. Haber called the group's attention to the necessity for evaluating the various insignia designs by a single evaluation index which was constructed by giving equal weights to the results obtained on the various insignia with the size series, the ground glass series, and the moving target series. He suggested that the performance of the various insignia in a particular situation might require determination of the most appropriate experimental test and application of the particular test results indicated.

Dr. Blackwell remarked that one aspect of the data seemed curious. He called allention to the fact that under normal conditions the black and white combination was easier to discriminate than the yellow and black combination. This result would be expected on the basis of the additional achromatic contrast available with the black and white insignia. The results presented demonstrated, however, that with the haze simulator, the yellow and black pattern was easier to discriminate for shape than the black and white. Dr. Blackwell asked Dr. Haber if he had any explanation for this curious reversal.

Dr. Haber commented that he did not know how to explain the effect.

Figure 1

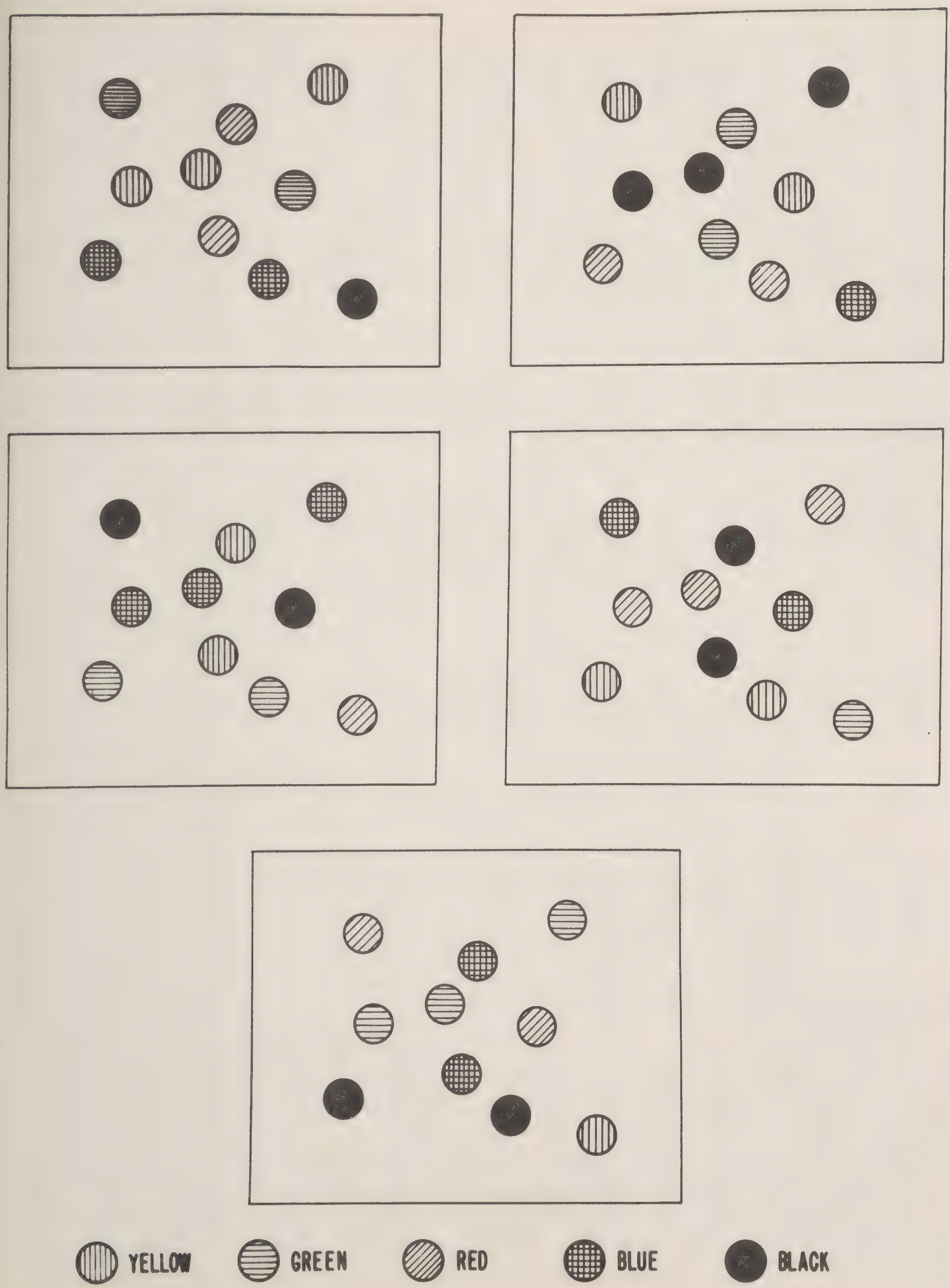


Figure 2

Color Combination	Total Score	Low Illumination		Ground Glass (Fog)		Conspicuity
		Color	Shape	Color	Shape	
Black - Yellow	6.71	1.29	0.43	1.36	1.68	1.95
Black - White	7.01	0.89	0.27	1.63	1.71	2.51
Yellow - Red	8.11	1.42	0.90	1.73	2.70	1.36
Red - Green	8.46	1.20	1.34	2.00	2.16	1.76
Yellow - Blue	10.35	2.16	0.88	3.47	1.76	2.08
White - Red	10.57	2.02	0.35	3.57	2.71	1.92
White - Blue	11.14	3.78	1.49	1.43	1.79	2.65
Black - Red	12.18	2.70	3.68	2.06	1.82	1.92
Yellow - Green	12.33	2.42	4.50	1.60	2.01	1.80
Red - Blue	13.14	2.12	6.16	1.15	1.66	2.05
	100.00	20.00	20.00	20.00	20.00	20.00

Figure 5

Figure 4

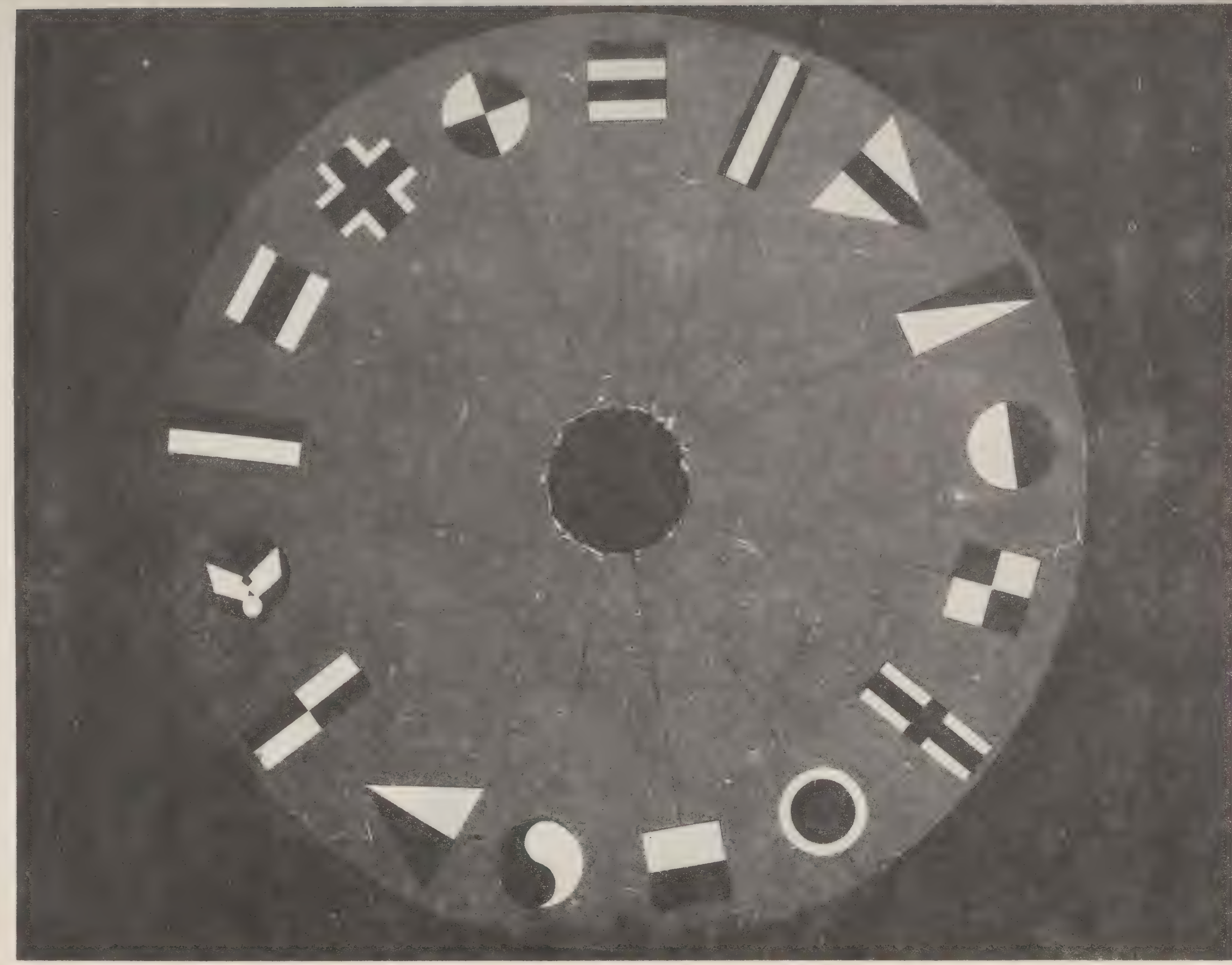
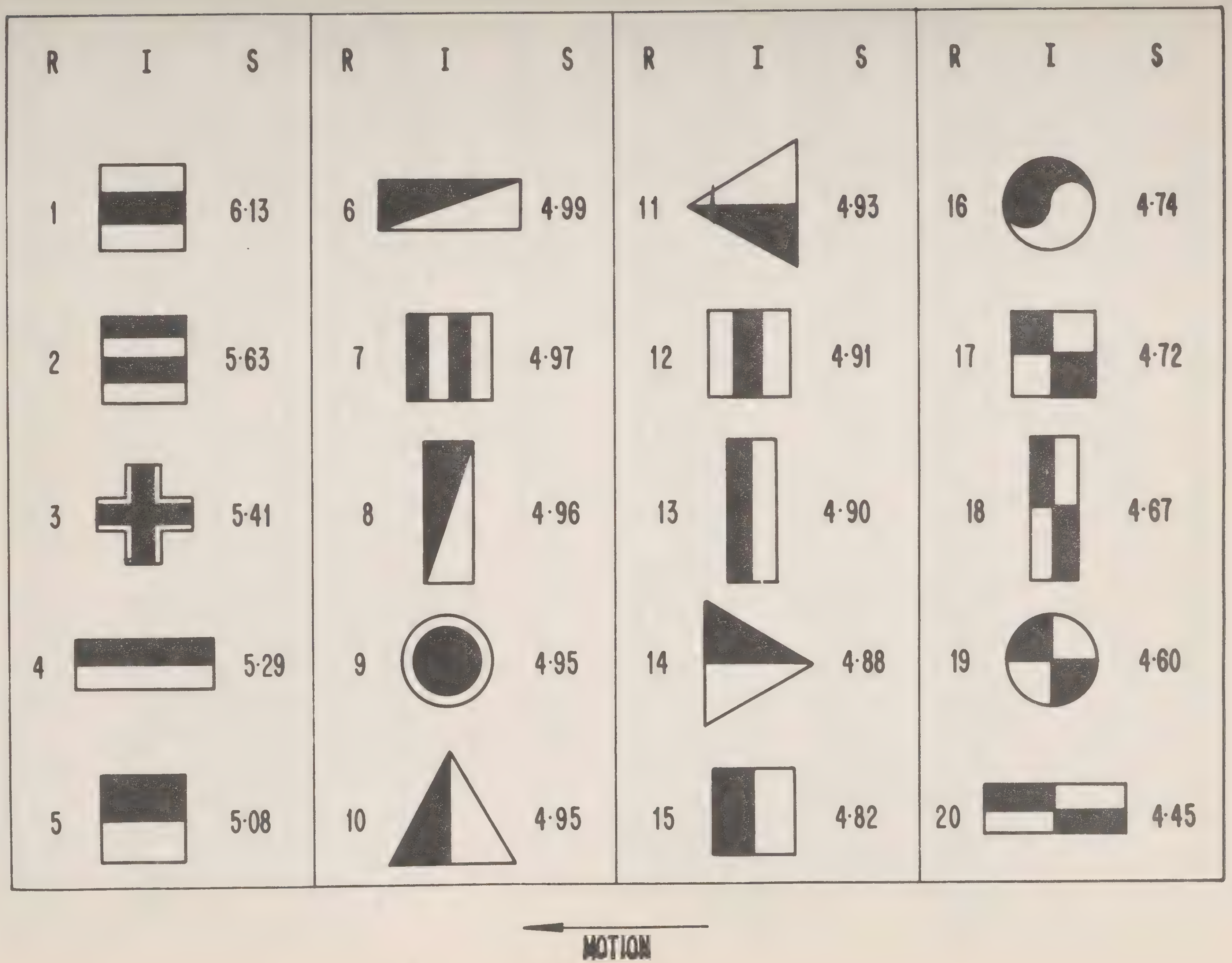


Figure 5


R I S
1 6·13
2 5·63
3 5·41
4 5·29
5 5·08
R I S
6 4·99
7 4·97
8 4·96
9 4·95
10 4·95
R I S
11 4·93
12 4·91
13 4·90
14 4·88
15 4·82
R I S
16 4·74
17 4·72
18 4·67
19 4·60
20 4·45
MOTION

THE EFFECT OF OPHTHALMIC FILTERS ON COLOR VISION

John L. Matthews, M.D.
San Antonio, Tex.

INTRODUCTION

The material presented herewith is derived almost entirely from the forthcoming report of the same title by Dr. Heinrich W. Rose and Dr. Ingeborg Schmidt (Project 21-02-040, Report 2, USAF School of Aviation Medicine). Credit for the investigative work is theirs solely.

As a background for future discussion, it is well to bear in mind the curve of cone sensitivity (Figure 1). The curve peaks sharply at about 550 millimicrons, in the yellowish-green zone, and falls rapidly and smoothly to either side.

The most popular filters for aviation use have long been of the type generally described as sage-green (Figure 2). A principal factor in their selection for flying personnel was the desire for a filter which yields maximum transmission at a point roughly corresponding with the peak of cone sensitivity. This was based on the theory that that filter is best which affords maximum luminosity with minimum energy transmission. The approximate coincidence of the curves of sensitivity and transmission has also been said to minimize color distortion.

During World War II a dark amber filter, rose smoke (Figure 3) was used extensively for sun glasses by the Air Force.

The transmission of typical gray filters is shown in Figure 4.

Recognizing the need for flying sun glasses and absorptive filters for ground personnel exposed to glare, the effect of various absorptive lenses on color vision must be determined. Most of the investigation in this field has been performed with subjects of known normal color perception. Noteboom[1] and Judd[2] found no change in subjective color sensations with change in the color of the illuminant or filters. Goldie[3] tested six subjects on a color lantern under daylight conditions; he showed that normal subjects perceive standard signals equally well with colored lenses and with neutral filters. Farnsworth[4] evaluated the effects of various colored and neutral filters on subjects of normal color vision, using the Farnsworth-Munsell 100 Hue and Farnsworth Dichotomous Tests. He found serious defects with the yellow and rose smoke filters, but concluded "Greenish lenses of no greater saturation than Calobar of 15% transmission would not impair color perception seriously." However, he recognizes that neutrality is desirable and should be the goal in producing absorptive filters.

In the selection of military personnel color vision tests have not been and are not now always administered with adequate care. Thus, we must recognize the presence of the color-defective aircrewman. Too, our present standards permit the qualification for air crew of certain mild deficiencies in color discrimination. Primarily with a view to determining the effects of colored lenses

on this group, Dr. Rose and Dr. Schmidt undertook this investigation.

METHODS

In this study the subjects were examined with a lantern test and a spectral color test. The lantern was the School of Aviation Medicine Color Threshold Tester (SAMCTT), described by Dr. Louise Sloan[5]. It offers eight single colored test lights (two reds, two greens, one yellow, one orange, one blue, and one white), each at eight different levels of intensity, or a total of 64 exposures. The levels differ from each other 0.3 in density or 50% in transmission. (As normally administered and interpreted, scores of 60-64 are classified as "passed," 50-59 as "color defective safe," and less than 50 as "color defective unsafe.") In this study the usual scoring method was not used. Rather, only six levels of brightness were used. When the subject wore no absorptive filter the six lower levels were used; with filter worn, the six higher levels were employed to compensate for the absorption of the filter. Scores are stated in terms of number of errors: Not more than 5 errors - "passed," 6 to 15 errors - "color defective safe," more than 15 errors - "color defective unsafe." Thus the categories by this method are comparable to but do not correspond exactly with those obtained by the approved scoring method.

As a spectral color test the Nagel anomaloscope was used, employing the Rayleigh equation. To secure and maintain cone vision and neutral color adaptation the subject studied a surface of color temperature 5500°K, 360 millilamberts brightness, for at least 5 seconds before each reading. Ten readings were taken in the attempt to match a yellow of 589 m u with a mixture of green 537 m u and red 665 m u. The instrument was so adjusted that the arithmetic mean of 400 normal subjects was 43. The readings were taken in arbitrary units but were transferred to quotients as suggested by v. Kries[6].

The v. Kries quotient is:

$$Qu_K = \frac{\dfrac{G_s}{R_s}}{\dfrac{G_n}{R_n}}$$

in which G_n and R_n are the mean luminous flux of green and red light employed by the normal, and G_s and R_s are the luminous flux of green and red light used by the subject.

The plotted quotients of 463 individuals (Figure 5) show three peaks, of which the middle is the highest. The arithmetic mean of this middle group is 43; its standard deviation (σ) 2.41. Normal color vision is herein considered to embrace $\pm 3\sigma$. The range $\pm 3\sigma$ corresponds to a range in quotients from 0.65 to 1.50. The group in the peak near quotient 0.25 are classified as protanomalous, those near quotient 4.0 as deuteranomalous. (The high ratio of anomalous individuals to normals is due to the inclusion of 13 protanomalous and 50 deuteranomalous persons.) Persons falling in the interval from 0.33 to 0.65 are termed subprotanomalous; those in the interval from 1.5 to 2.7, subdeuteranomalous. Proto-borderline normals and deutero-borderline normals lie just within the two limits of normal.

The effects of the following filters were studied: Ultrasin (25% transmission), Umbral (18%), Rose Smoke (10%), Yellow (26%), Neophan (26%), Calobar C (55%), Calobar D (42%), Ray-Ban 2 (51%), Ray-Ban 3 (33%), Wratten Neutral Density 0.6 (24%), Bausch and Lomb Neutral 3 (29%), and Neutralite (30%).

Tests on the lantern consisted of one run without filter worn and one run with each filter tested. On the anomaloscope 5 readings were recorded without filter worn and 10 readings with each filter.

RESULTS

Table A summarizes the results of the SAMCTT test. All subjects are borderlines who "passed" the test or deuteranomalous subjects classified as "passed" or color defective safe." All are acceptable as pilots. In general, the number of errors is too small for statistical evaluation. Certain features are of interest, however. Both greenish and yellowish-brown filters shift the color discrimination of some persons to lower classifications, and in some cases the deterioration is serious. Two deuteranomalous subjects were shifted from "passed" to "color defective unsafe" by green glasses. On test of 13 deuteranomalous subjects with a red test light (Corning 2424), the use of green glasses increased the number of errors 10 times, a deterioration even more damaging than occurred with brownish filters (2 errors without filter; 20 errors with green filters; 10 errors with brownish filters). With a green test light (Corning 3441), the use of brownish filters approximately doubled (5.7 errors) and green glasses quadrupled (11.7 errors) the number of errors obtained without filter (3 errors).

Gray glasses were tested in a smaller number of persons, and in some cases the classification was shifted from "passed" to "color defective safe." In general, the influence of the gray glasses on the number of errors recorded was less than that of the colored filters.

Table B summarizes the results of tests with colored filters and the anomaloscope. The tests with normal and deuteranomalous subjects were evaluated; the differences between the measurements with and without absorptive glasses were great enough to meet the level of significance of 0.23%. The other groups were too small for statistical evaluation. Figure 6 demonstrates the shift of quotients for protanomalous, normal, and deuteranomalous persons using greenish and brownish filters. Even though the anomaloscope test does not simulate the conditions of identifying colored signals, it is a very exact test yielding consistent results which can be statistically evaluated. With all colored filters a significant shift in quotient is obtained. The greenish filters always shift in the protanomalous direction; the brownish filters always shift in the deuteranomalous direction. Even the middle normals are shifted markedly, e.g., Ray-Ban No. 3 shifted the quotients outside the normal range (Table B). As was seen in Table B, the "proto-forms" (proto-borderline normals, subprotanomalous, and protanomalous) are shifted by green glasses away from the normal quotients, and by brownish glasses toward normal values. Figure 7 demonstrates the shift of quotient of proto-borderline cases by colored glasses. Contrariwise, the "deutero-forms" (deutero-borderline normals, subdeuteranomalous, and deuteranomalous) are shifted away from normal quotients by brownish glasses and toward normal values by green glasses. Such effects on the deutero-borderline normals is shown in Figure 8.

A small group of subjects was studied by the anomaloscope test to determine the effect of various "neutral" filters. The results in 10 normal subjects were evaluated. The responses of proto-borderline normals, deutero-borderline normals, and deuteranomalous subjects (3 subjects in each group) could not be evaluated statistically. However, Figure 9 shows the mean quotient of the normals and its shift by gray glasses. Figure 10 indicates the shift in the prot-borderline normal group.

DISCUSSION

It was observed that, with the anomaloscope test, the quotients of proto-forms and deutero-forms were shifted toward normal by brownish glasses and greenish glasses respectively. This seems to justify the use of brownish glasses by protoforms and green glasses by deutero-forms. However, it was also observed that the use of green glasses worsened the scores of the deutero-forms in the lantern test. This is explained by the absorption of green filters in the relatively insensitive red region of the spectrum. Even in deuteranomaly the loss of brightness of red light is more damaging than the slight relative gain in brightness of green light. Hence, we conclude that green glasses produce a significant deterioration of discrimination in all types of color vision. The performance of the proto-forms engaged in distinguishing dim red signals in bright environment may be improved by the wearing of brownish lenses, but it is doubtful if the recognition of color quality is improved. To provide brownish lenses for the protanomalous is impractical because they comprise only about 1% of the male population and most of them are disqualified as "color defective unsafe."

---

1. Noteboom, E., Objektive und subjektive Aenderung von farbigen Lichtern un Pigmenten durch einige farbige Augenglaeser. Zeitschr. Instrumentenkunde, 55: 317, 1935.

2. Judd, D. B., Hue, Saturation, and Lightness of Surface Colors with Chromatic Illumination. J. Optic. Soc. Amer., 30: 2, 1940.

3. Goldie, E. A. G., Note on recognition of coloured light signals through Crookes (neutral) and greenish tinted filter (Chance 351/13) for use in anti-glare spectacles. Roy. Air Force, P.L./38/35, Nov 17, 1943.

4. Farnsworth, D., The effect of colored lenses upon color discrimination, Color Vision Rep. No. 9, 1945, N.L. Sub -1-CV-17, BUMed X-502 (av-269-p), Med. Res. Dept., US Submarine Base, New London, Conn. 3 Sept 45.

5. Sloan Rowland, L., Selection and validation of tests for color vision - The color threshold lantern as a quantitative test for red-green color deficiency, Proj. No. 137, Rep. No. 5, 20 Oct 1943.

6. v. Kries, J., Zeitschr. Sinnesphysiol. 13: 285, 1897; 19: 65, 1899, 50: 137, 1919.

DISCUSSION:

Dr. Hulburt stated his interest in whether it could be shown that a completely non-selective neutral filter would be substantially better as an ophthalmic filter than the non-selective "neutral" filters at present available. He suggested that attempts be made to use physical reduction methods to determine whether truly non-selective filter would permit the eye better performance than available neutral filters.

Dr. Sloan asked whether the "neutral" filters affected the lantern scores as well as the anomaloscope scores.

Dr. Matthews replied in the affirmative.

Dr. Sloan then asked whether the effect could be explained on the basis of the brightness reduction introduced by the filters.

Dr. Matthews replied in the negative.

Dr. Imus asked whether a non-selective material was used which was as good as the N-4 material.

Dr. Rose reported that the material he used was N-3, which is known to be less selective than N-4. He reported that since there was a measurable effect with the N-3 material, that an even worse effect would be expected with the N-4 material.

Dr. Imus expressed surprise at this result since, he stated, Dr. Judd had shown that the N-4 material did not have an appreciable influence upon color discrimination.

Commander Farnsworth asked whether the difference obtained was significant.

Dr. Rose reported that he believed it was significant in the case of the anomaloscope data.

Commander Farnsworth asked concerning the significance of differences in the case of the lantern scores.

Dr. Rose reported that indeed the effect was small, although more errors were present on the random test in the case of the neutral filter. He agreed that it was impossible to conclude too much until more borderline cases had been tested.

Commander Farnsworth stated his conviction that any influence presently available neutral filters have upon color perception is not of practical importance. Commander Farnsworth thanked Dr. Matthews and Dr. Rose for allowing him the opportunity of reading their paper in advance of the meeting. He reported that his criticisms of the paper had been transmitted to the authors before the time of the meeting. Commander Farnsworth then stated his criticisms of the study as follows: He attacked the meaning attached to the anomaloscope results. He stated that actually the effect of the filters upon anomaloscope data merely constituted the use of the anomaloscope as a visual spectrophotometer. He stated that as such, influence on the anomaloscope scores is no index of the degree to which the eye can adjust itself to a new neutral

level. Commander Farnsworth stated his conviction that what should be measured is the degree to which the eye can adapt itself to a new neutral such as must occur when a slightly selective filter is worn before the eyes. Decrement in subsequent color perception is a measure of the deleterious effect of the filter used before the eye.

TABLE A

Classification of Persons into "Passed", "Color Defective Safe" and "Color Defective Unsafe" by the SAM Color Threshold Tester When Colored Filters are Used.

Filter	Number of Persons								
	6 Proto-borderline Normals			5 Deutero-borderline Normals			13 Deuteranomalous Subjects		
	Passed	Col. Def. Safe	Col. Def. Unsafe	Passed	Col. Def. Safe	Col. Def. Unsafe	Passed	Col. Def. Safe	Col. Def. Unsafe
Ray-Ban No. 3	6	0	0	4	1	0	5	5	3
Ray-Ban No. 2	5	1	0	4	1	0	5	5	3
Calobar C*	2	0	0	0	2	0	2	5	2
Calobar D	5	1	0	4	1	0	3	7	3
No Goggles	6	0	0	5	0	0	8	5	0
Neophan*	5	0	0	4	1	0	7	5	1
Rose Smoke	6	0	0	4	1	0	5	8	0
Ultrasin	6	0	0	5	0	0	7	6	0
Umbral	6	0	0	4	1	0	6	3	4
Polaroid Yellow*	3	2	0	1	4	0	4	4	5

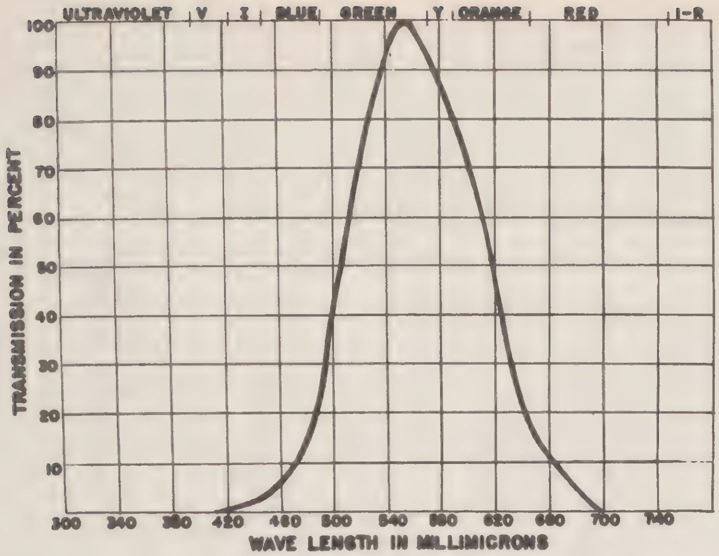
*Tests with this filter did not include all persons.

TABLE B

Colored Filters. Mean Values of Anomaloscope Quotients.
Each Person Made Ten Readings With Each Filter

Filter	10 Normals	Two Proto-borderline Normals	Four Deutero-borderline Normals	Two Protanomalous	Ten Deuteranomalous
Ray-Ban No. 3	0.61	0.45	0.85	0.152	2.32
Ray-Van No. 2	0.68	0.49	1.02	0.147	2.70
Calobar C	0.68	--	1.00	0.185	2.64
Calobar D	0.68	0.47	0.88	0.155	2.34
No Goggles	0.94	0.76	1.35	0.245	3.70
Neophen	1.15	1.00	1.70	0.301	4.55
Rose smoke	1.39	1.14	2.00	0.332	5.20
Umbral	1.67	1.23	2.35	0.410	5.80
Polaroid Yellow	2.23	1.80	3.20	0.520	7.70
4 Greenish Filters	0.66	0.47*	0.93	0.160	2.52
No Goggles	0.94	0.76	1.35	0.245	3.70
4 Brownish Yellowish Filters	1.72	1.35	2.48	0.396	6.04

*3 Filters



CURVE OF RETINAL SENSITIVITY

Figure 1

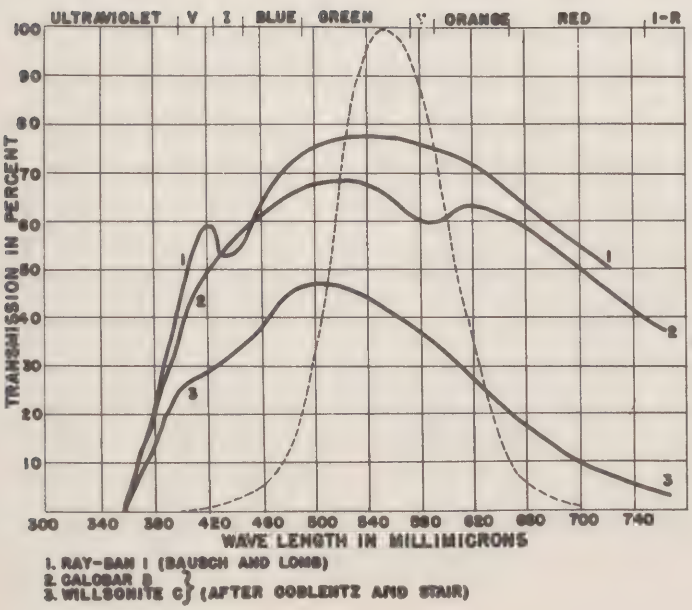


Figure 2

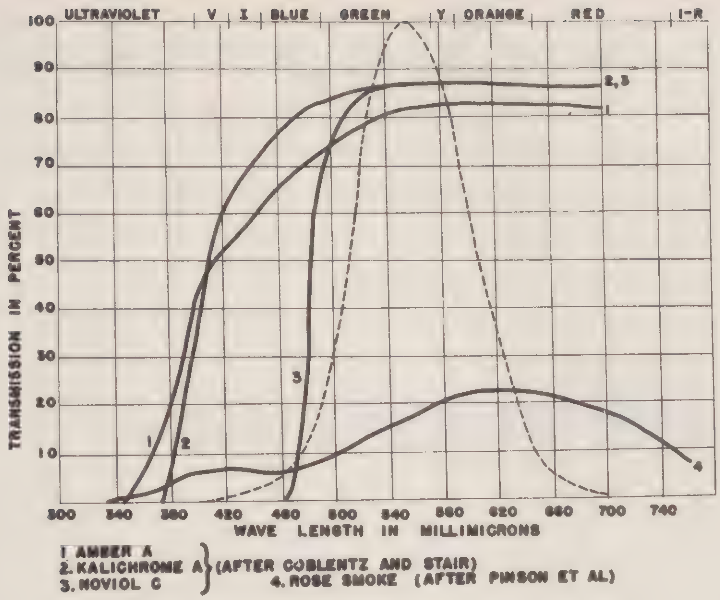


Figure 3

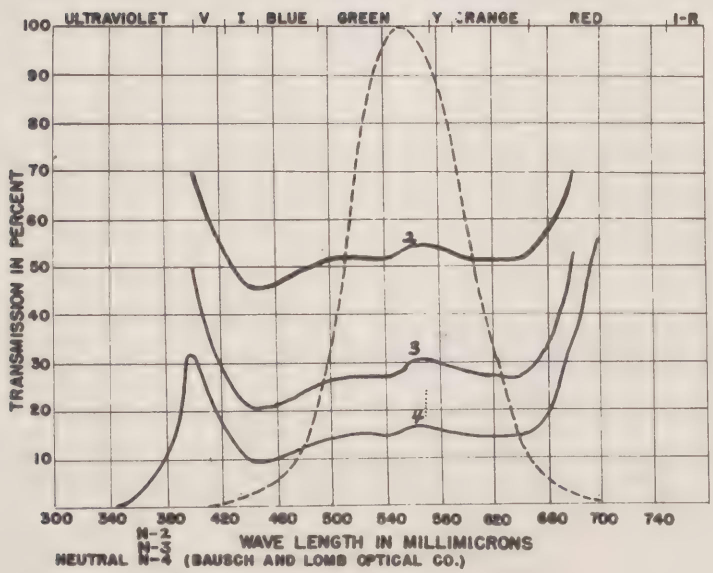


Figure 4

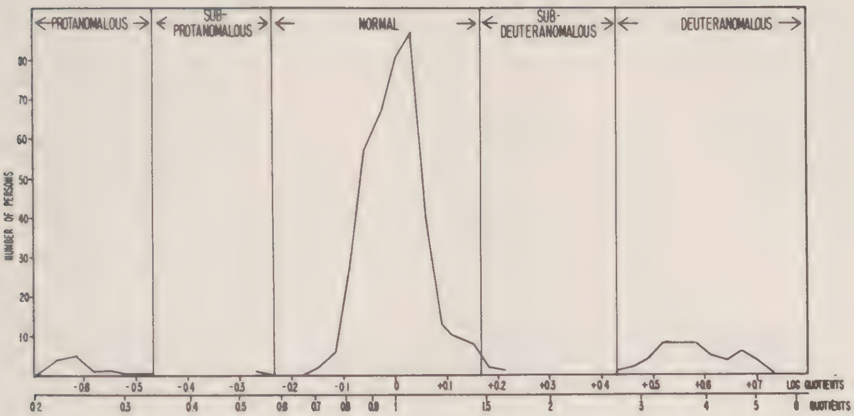


Figure 5

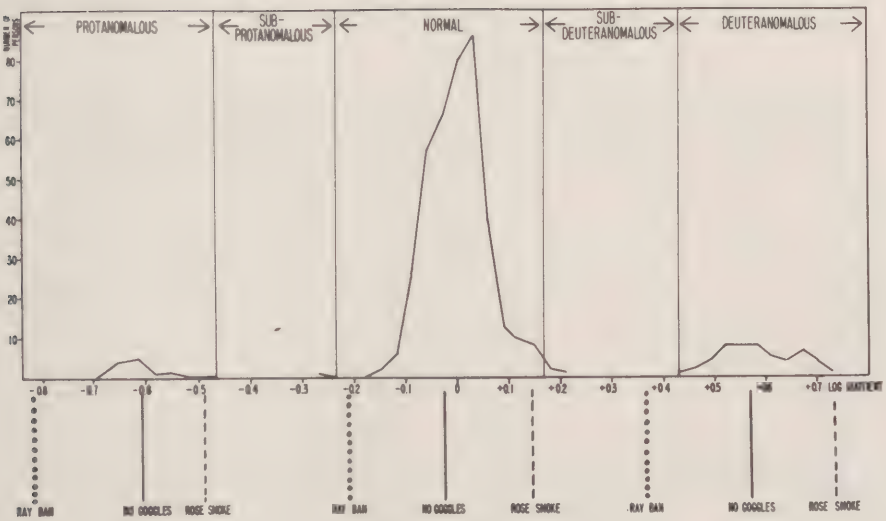


Figure 6

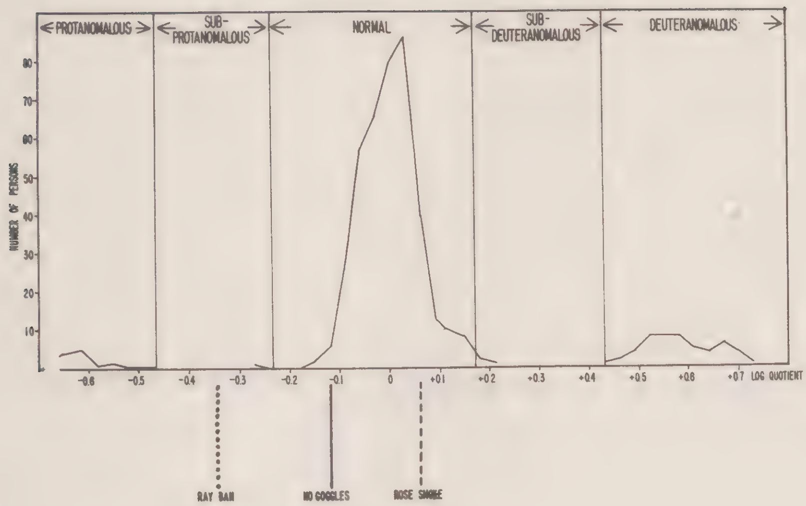


Figure 7

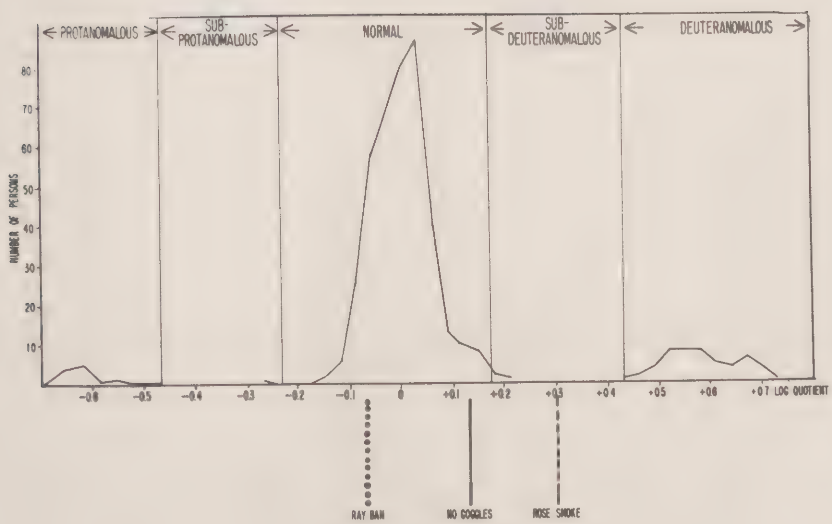


Figure 8

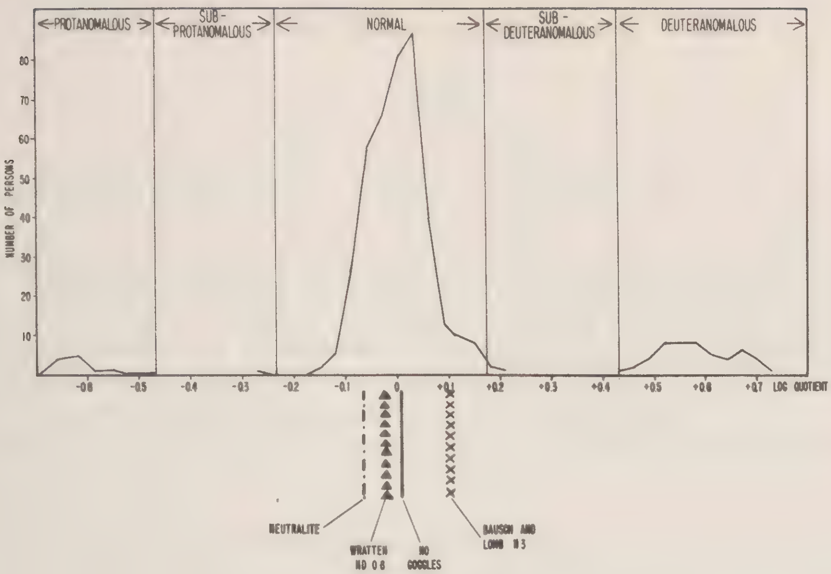


Figure 9

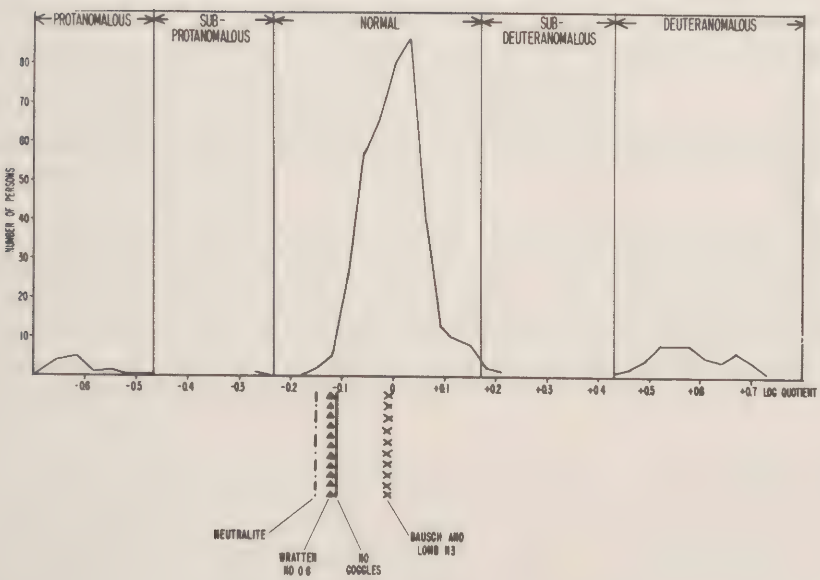


Figure 10

RUNWAY MARKINGS AND IDENTIFICATION LIGHTING

by
Heinz Haber, Ph. D.

and
Siegfried S. Gerathewohl, Ph. D.

I. A Study of Runway Markings, Report 1, Project No. 512

Fog and haze are some of the most serious handicaps in aviation. Even the pilot of a radar-guided ship appreciates the use of his eyes at least in the very last moments of a landing approach. It is worthwhile to help the pilot orientate himself, possibly by means of a characteristic marking of the runway perceptible through haze and thin fog. The problem is to find out the most efficient marking pattern to serve the above outlined purpose.

The marking pattern has to meet various demands under various conditions such as:

High visibility through haze and thin fog
High visibility under various conditions of illumination
Orientational help as to lateral and longitudinal position of the landing aircraft
Proper size and shape to be perceived and recognized from large and small distances as well as under various angles
The elements of the pattern must be unambiguous and foolproof as to their directory sense
Simplicity of shape and arrangement to avoid any sort of confusion
Simplicity and economy of construction and maintenance

It is obvious that any marking pattern to meet these demands necessarily will be a compromise. Thus the problem is to find out the optimum of the different technical and psychological factors involved.

In processing the above mentioned research some experiments using model markings were made in a room filled with steam of relatively high density. These experiments, however, proved to be very unsatisfactory basically for two reasons:

1. The density of the steam entering the room through an inlet varied widely in different parts of the room as well as from one minute to the other.
2. The test subjects were unable to bear the humidity and temperature in the steamy room for the time required to carry out the numerous tests, without considerable fatigue. The dependability of the results was necessarily rather questionable.

In search for another way to a solution it was remembered that sections of ground glass were occasionally used to blurr vision. A detailed theory of this well known blurring effect, however, was desired in order to decide whether the use of a ground glass was feasible in this case. Fortunately, it can be shown that a ground glass of proper characteristics is capable in simulating the effect of fog as evidenced by the following brief theoretical development.

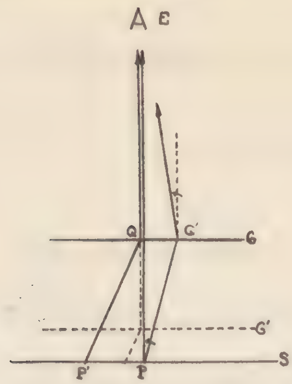


Fig. 1

Consider, according to fig. 1, a plane ground glass G above a horizontal plane S being in a parallel position. P is a point of an object located on S, from which a ray of light is emitted straight upward. The ground glass transmits the ray at the point Q and the ray reaches the eye E of the observer looking straight downward. Due to the fine structure of the ground surface of the glass, rays of light reaching the point Q at a slant angle will be scattered and rendered able to travel along Q - E and to reach the eye as well. The picture of the point P, therefore, will be overlapped by pictures of innumerable pictures P' in the proximity of P, thus causing the familiar blurr. There can be defined a characteristic angle ϵ which limits a circular area around the point P containing all the points P' contributing to the blurring. Beyond this area as limited by the angle ϵ, the scattering effect of the ground glass will not be sufficient enough to bend light into the direction Q - E still to be perceived by the observer. It is needless to say that this angle ϵ is by no means a sharp limit. The angle ϵ will be a characteristic constant depending on the fine structure of the individual ground glass, on its uniformity and cleanliness.

The circular area around P as limited by the angle ϵ may be taken as a measure for the amount of blurring as caused by the ground glass under the described conditions. This area may be called diffusion patch.

Decreasing the distance between the ground glass G and the plane S - as indicated by the broken line G' in fig. 1 - the size of the diffusion patch will decrease as well, since ϵ is still the same. Thus a change of the distance between ground glass and the object will result in a change of the blurring effect caused by the ground glass.

It has to be pointed out that the above described conditions do not express all the blurring the ground glass is able to produce. A ray of light which leaves the point P subtending the angle ϵ' with the vertical ray PQ, will be scattered by the ground glass at the point Q' and is allowed to propagate further along Q' - E, as soon as the condition

$$\epsilon \leq \epsilon' + \epsilon'' \qquad (1)$$

is fulfilled. In most cases concerned, however, one deals with the condition GE $\gg$ GS, which makes the angle ϵ'' almost equal to zero. Thus eq. (1) is reduced to $\epsilon \approx \epsilon'$ and the diffusion patch on the ground glass will be almost equal to that on the plane S. This shows that one deals with a fairly workable approximation

in using the size of the diffusion patch in order to measure the amount of blurring. By this approximation a cumbersome mathematical development such as integrating between the limits given by the two diffusion patches, can be avoided.

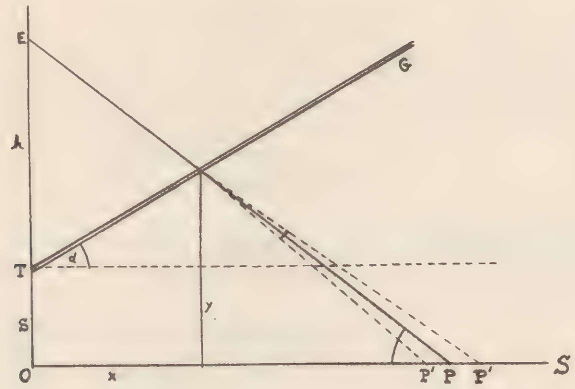


Fig. 2

Working on the base of the assumptions outlined above, a formula can be derived which gives the amount of blurring caused by a section of ground glass in any position relative to the plane S. Referring to fig. 2 one has:

O	Origin of the system of co-ordinates
S-S	X-axis, horizontal cross-section of plane, bearing the object P
E	Eye of observer lying on the y-axis
G	Ground Glass
α	Slope of ground glass
T	Point of intersection between G and y-axis
s	Ordinate of T
h+s	Ordinate of E
r	Abscissa of P
Q	Point of intersection between G and line of sight E - P
x,y	Co-ordinates of Q
w	Line segment QP
ϵ	Characteristic limiting angle of scattering
ϕ	Angle subtended by line of sight and x-axis
P-P'	Cross-section of diffusion patch

If the ground glass is moved up and down and its inclination changed, the quantities s, α, x, y and w will become variables. Displacements of the eye and of the point P will make h and r also become variables. One faces the problem to express w as a function of the variables characterizing the position of the ground glass, of that of the eye and of that of the object, respectively. The variables concerned are s, α, h and r, respectively. In this development of the function

$$w = f(s,\alpha,h,r) \qquad (2)$$

it is desirable to eliminate x and y, since they are dependent on the first set of variables.

According to plane geometry one has:

$$y = x \tan \alpha + s \tag{3}$$

as well as

$$w = \sqrt{(r-x)^2 + y^2} \tag{4}$$

Introducing eq. (3) into eq. (4) yields

$$w = \sqrt{(r-x)^2 + (x \cdot \tan \alpha + s)^2} \tag{5}$$

x can be eliminated from eq. (5) by means of the following relation:

$$\frac{x}{h-(x \cdot \tan \alpha + s)} = \frac{r}{h+s} \tag{6}$$

which is evidenced by comparison of the respective similar triangles in fig.2. Eq. (6) is a linear equation in x whose solution is

$$x = \frac{r(h+s)}{h+s+r \tan \alpha} \tag{7}$$

Introducing eq. (7) into eq. (5) yields the above mentioned function:

$$w = \sqrt{r^2 \left[1 - \frac{h+s}{h+s+r \cdot \tan \alpha}\right]^2 + \left[\frac{r(h-s) \cdot \tan \alpha}{h+s+r \tan \alpha} + s\right]^2} \tag{8}$$

The diffusion patch presents itself as an ellipse being a section of a cone. The area of this ellipse can be readily computed by use of w, ϵ and ϕ :

$$A = \frac{\pi \epsilon^2}{4} w^2 \cdot \operatorname{cosec} \phi \tag{9}$$

cosec ϕ in eq. (9) can be eliminated by use of the relations

$$\cot \phi = \frac{r}{h+s} \tag{10}$$

$$\operatorname{cosec}\phi = \sqrt{\cot^2\phi + 1} = \sqrt{\frac{r^2}{(h+s)^2} + 1}$$

(11)

Introducing eqa. (8) and (11) into eq. (9) yields the area of the diffusion patch as a function of the variables s, α, h and r as given by the function (2). According to the foregoing development one has

$$A = \frac{\pi\epsilon^2}{4}\left[r^2\left(1 - \frac{h-s}{h+s+r\cdot\tan\alpha}\right)^2 + \left(\frac{r(h-s)\tan\alpha}{h+s+r\cdot\tan\alpha} + s\right)^2\right]\sqrt{\frac{r^2}{(h+s)^2} + 1}$$

(12)

In order to express the rate of blurring in terms of visibility, an expression has to be found giving the visibility as a function of the area of the diffusion patch (12). Obviously an expression of the form:

$$V = 1 - e^{-\frac{c}{A}}$$

(13)

serves this purpose, since the visibility will be equal to 1, if A = 0, and it will be equal to zero, if A = ∞. c is a constant whose value is determined by the characteristics of the ground glass as well as by the scale to be used for V. Introducing eq. (12) into eq. (13) yields the final expression:

$$V = 1 - e^{-\frac{4c}{\pi\epsilon^2}\cdot\frac{}{\left[r^2\left(1 - \frac{h-s}{h+s+r\cdot\tan\alpha}\right)^2 + \left(\frac{r(h-s)\cdot\tan\alpha}{h+s+r\cdot\tan\alpha} + s\right)^2\right]\sqrt{\frac{r^2}{(h+s)^2} + 1}}}$$

(14)

Eq. (14) may be compared to a formula originating in the meteorological theory of visibility:

$$H = k\left(i - e^{-a_o\cdot r}\right) \; *$$

(15)

* Friedrich Loehle, Sichtbeobachtungen vom meteorologischen Standpunkte (Observations of visibility from a meteorological point of view) Berlin, 1941, Verlag Juluis Springer.

whence H represents the loss of contrast of a black object caused by fog as a function of the distance r; k and a_o being constants. Since the area of the diffusion patch in eq. (12) is related to this loss of contrast, the similarity of the blurring effects caused by fog and by a

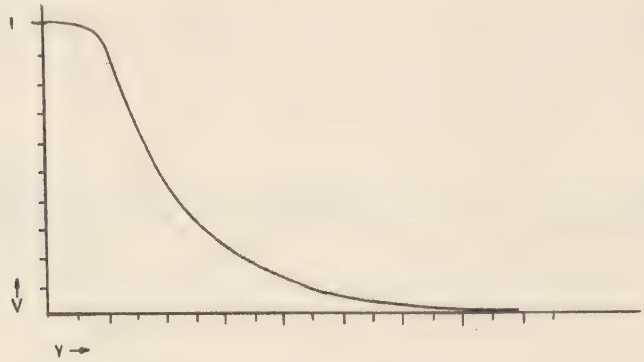


Fig. 3

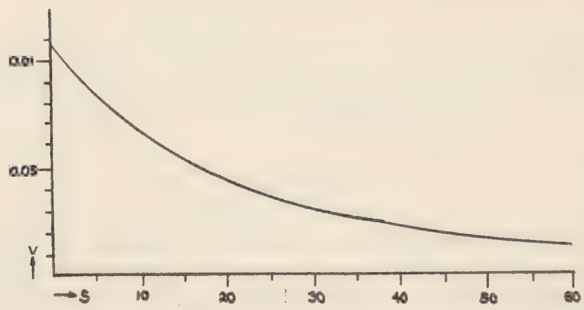


Fig. 4

ground glass, respectively, is obvious. Fig. 3 shows an evaluation of eq. (14) i.e. the decrease of visibility with increasing distance r of the object behind the ground glass. The scale on the x-axis is arbitrary, the ordinate gives the vision in decimal notation. A similar curve can be obtained by evaluating the meteorological expression (15) which would represent the decline of vision caused by fog.

In possession of the above outlined theory a section of a ground glass was used to carry out the testing of the efficiency of different elementary markings. In order to approximate the situation of an aircraft landing in poor visibility conditions, a model runway was built which is to be viewed through a piece of ground glass. (See fig.5.) The model runway consists of an endless belt running over two rollers at either end, driven by a motor attached to an adjustable gear. The belt bears a white paper strip carrying the black model markings to be tested. The combination black-white was chosen to procure the best of contrast. The white paper strip is 58 mm. wide representing a scale of 1:1, 150 in dealing with a runway of 200 ft. width. In this way a situation is produced which shows the observer at rest and the runway moving, while in actual landing operation the pilot moves over resting ground. In spite of this difference of situation, the psycho-

logical conclusions drawn from the experiments are valid. The test subject's head rests on a chin rest fixing the position of the eyes. The ground glass is mounted in a frame which can be shifted up and down by means of a gear manipulated by a knob. The elevation of the ground glass can be read on a scale. The inclination of the ground glass can be varied and read as well.

Fig. 5

A test was accomplished in the following way: the test subject views the model runway through the ground glass slanted at an angle of 45°. The ground glass is first set in the highest position blurring the distinctness of the model runway almost altogether. The test subject then runs the ground glass down to the point where the markings become just recognizable. This recognition threshold was considered as being reached, as soon as the test subject was able to indicate the correct direction of several groups of markings passing by. Ten consecutive determinations of the recognition threshold of each marking were made in this manner. The mean of these ten determinations expressed in terms of the elevations of the ground glass, was considered to be the recognition threshold of the respective individual markings, so far as the individual test person was concerned.

The runway was illuminated by a 100 Watt lamp through a Corning Daylight Filter (color temperature of about 5500°) producing a brightness of 4.12 millilambert on the runway. The belt revolved at a rate of 6 per minute representing a landing speed of about 80 mi/hr.

For the choice of the markings used for the experiments, the following had to be considered: 1. the markings had to be highly efficient concerning shape, size and gestalt; 2. the markings had to exhibit an unambiguous demonstrative value. The basic element of a marking supposed to demonstrate direction in general, must be triangular in its various modifications such as arrows, angles, triangles themselves and other related outlines. In order to confine the experiments to studies on shape and form alone, colors were disregarded. In addition to this, preliminary results of experiments with colors by means of the ground

glass, have shown, that the black-white and the black-yellow combinations generally rate highest in perceptibility through fog.

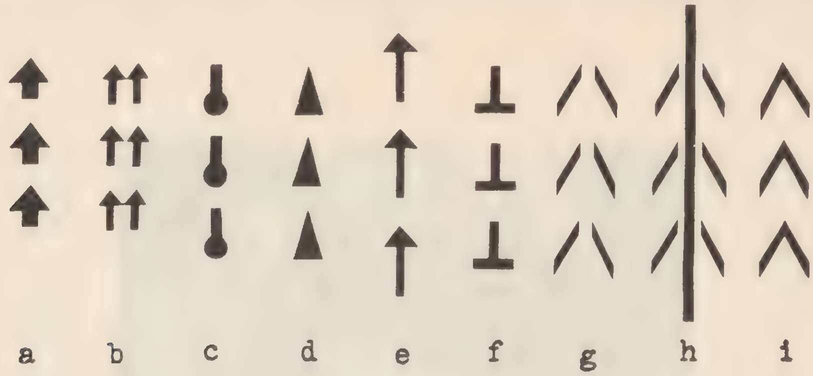


Fig. 6

With respect to these demands nine different elementary markings were chosen as given in fig.6 a - i.

Each elementary marking covers an area of 187.5 sq. mm. This was a necessary condition in order to obtain comparable scores for the different markings. (The central bar in marking "h" fig.6 is not included in the constant area.)

Each marking was run ten times by ten different test subjects with normal visual acuity, in the above described manner. One hundred readings for each sign were thus obtained. Table 1, column 1 and 2, shows the averaged results of the total of 900 experiments.

The figures in the column 2 of table 1 are arbitrary numbers which do not allow an immediate comparison of the scores. The law of eq. (14) however, provides conversion of these numbers into indications of visibility, expressed in standard terms of visual acuity required to recognize the different markings under identical conditions. A standardization of the ground glass and the conditions used, was necessary for this purpose. The standardization was carried out by means of a Near Vision Test Chart according to J.E. Lebensohn. The chart was placed beneath the horizontal ground glass, the eye of the observer being 350 mm. above the chart. The illumination of the chart was the same as outlined above,

Table 1

1	2	3		4
Marking	Reading a	Required Visual Acuity		Reduced Recognition
		Dec. Not	Dist. Equval	Distance in feet
a	13.93	0.0547	20/365	100
b	24.76	.0367	20/545	123
c	44.14	.0209	20/956	162
d	45.17	.0201	20/996	165
e	56.31	.0156	20/1,280	187
f	58.51	.0149	20/1,340	192
g	64.65	.0128	20/1,560	207
h	64.69	.0128	20/1,560	207
i	64.95	.0126	20/1,590	208

the brightness of the target, however, being 2.6 millilambert in this case. The ground glass was used in a position characterized mathematically by $r = 0$, $\alpha = 0$, and $h + s = 350$ mm., s being the independent variable. The elevations s required to render the different lines of the chart readable, were measured by running ten test subjects. The results obtained were averaged and used in order to determine the constant c in eq. (14). Using $\epsilon = 3^\circ\!.5$ (0.06 radians) the value $c = 0.00235$ was obtained. This value standardizes the ground glass for any other positions as well. The 9 different markings were run under the conditions: $r = 30$ mm., $h + s = 250$ mm., $\alpha = 45^\circ$, s being the independent variable. Introducing these values into eq. (14) yields a function standardizing the scores of the different markings in terms of visual acuity.

An evaluation of eq. (14) under the above mentioned conditions was carried out. The result is the standardization curve shown in fig.4 which allows to convert the elevation s of the ground glass in Millimeters (abscissae) into the required visual acuity expressed in decimal notation (ordinates). Using this graph, the scores of the 9 markings were converted into visual acuities and listed in column 3 of table 1 for each marking.

There is another way to express the efficiency of the different markings which is more closely related to the purpose the markings are supposed to serve. One has to assume a fog of a certain constant density* which may be defined by the fact that the threshold of recognition of marking 6 a lies at a distance of 100 ft. Underlying these conditions, the recognition distances of the other 8 markings can be calculated assuming that all the markings have the same relative proportions as in the experiments. In this calculation, the decrease of the visual angle subtended by the markings at different distances must be taken into account. The result of this calculation giving their efficiency in terms of reduced recognition distance, are listed in table 1, column 4.

The results show that there is a considerable difference in efficiency of the various markings. Obviously the markings characterized by compactness, rate low, while markings showing dissolved features, spread over a wider area, are distinguished by high scores, provided a certain width of the individual elements composing the marking is given. According to these findings, the simple angle (fig.6 i) meets the demands in the best way. As to its special outlines the following may be said: the angle is derived from the equilateral triangle; this geometric figure is of a most harmonic form and has the advantage of maintaining its triangular features during perspective distortion in the best way. The legs of the angle were cut off in order to enhance the directional value of the marking.

The above described experiments have resulted in finding a marking of highest efficiency which now may be used in various arrangements of runway marking patterns to meet the present demands.

As far as the longitudinal orientation is concerned, it is advisable to make a threefold subdivision of the runway, the three thirds being equal in length. It is the purpose of this subdivision to inform the pilot of an approaching aircraft whether a landing might be possible. Generally spoken, a plane may safely land if touching the runway either in the first or the middle third. Since a runway is used from either end as depending upon wind condition, it is self-explanatory, that the marking patterns of the two outer thirds must be mutual mirror images.

For the arrangements of the markings and the construction of the entire pattern, the following points have to be considered:

* This fog would be characterized by eq. (14) with $c = 0.00235$.

1. The two outer thirds must be marked in such a way that they produce an attractive or a repelling psychological effect, respectively. This effect is readily produced by use of the triangular shaped markings, since the angles pointing toward the observer are likely to cause increased caution, an effect which is rather enhanced by the motion of the approaching aircraft.
2. It seems to be important to reinforce the psychological effects by a marked emphasis of the inner parts of the outer thirds adjacent to the central part. These emphasized markings are to represent a reliable warning to either land or to refuse.
3. There is a general necessity of avoiding any overloading the runway with markings. If a pattern is too complicated it may cause confusion and hinder recognition of obstacles. This holds true in case of clear vision when the entire runway can be seen as well as in case of impaired vision. Ten individual markings on either third is recommended as the upper limit.
4. The size of the individual markings must be well considered. Large markings have the advantage of good visibility from high altitudes and in poor weather conditions; on the other hand they hardly can be perceived as units from small distances and at slant angles thus loosing their directional value. A compromise between these demands has to be made.
5. The size of the elementary markings all over the entire pattern as well as the distances between them should be kept equal, since any dimensional standardization of objects on the ground are a substantial help to increase depth perception by the use of the size of the retinal image. The distances between the individual markings must be large enough to allow the pilot to perceive it with certainty. Too close a distance may hinder perception of the unit target or may even result in a disturbing flicker effect while viewing the pattern, especially at high landing speeds.
6. In dealing with runways of various brightnesses (albedo) and colors, one has to procure the highest possible contrast. Black and white will serve this purpose best. Furthermore, black and white present no difficulties of standardization and show no change of their values under various states of illumination as opposed to colors. Occasionally it might be necessary to paint the elementary parts of the pattern in black upon a white surrounding or vice versa. In case of a snow cover, an emergency marking can be easily spread out in black dust of coal, ashes or dirt.

As far as the lateral orientation is concerned, the following points have to be considered:

1. Under good visibility conditions it is desirable to give the pilot a help in aiming at the center of the runway from greater distances. This can be procured by long-stretched, linear elements incorporated in the marking pattern. In addition to this, the alignment of the points of the angles serve the same purpose, while the slant legs produce a "funneling" effect forcing the pilot toward the central line of the runway. Emphasis of the general longitudinal directive can be placed preferably upon the central part free of individual markings.
2. Any marking of the lateral limits of the runway is superfluous. The entire pattern will be of no use anyway, if the visual distance limited by fog is less than about one third of the runway width. In cases of a somewhat better visibility, however, the pilot will be able to accomplish a lateral orientation.

Three different recommendations of runway marking patterns, giving credit to the above outlined considerations are presented in fig.7 as well as in three paper models attached to this report. The scale of the model runways is 1:1,150, representing a runway 200 ft. wide and 4,450 ft. long (Eastern runway, Randolph Field, Tex.).

Sample 1:

Ten individual markings, of small size, per outer third, arranged to form a large arrow pointing toward a broad central line which stretches over the entire length of the central part.

Advantages:

Simplicity of arrangement, clearness and perspicuity of the entire runway. Economy and ease of construction and maintenance,

I II III

Fig. 7

since a small total area is to be painted.

Disadvantages:

Small size of the individual markings with corresponding low visibility.

Sample 2:

Ten individual markings, of medium size, per outer third, alignment arranged in four groups of 1, 2, 3, and 4 respectively, upon approaching the central part marked by two wider stripes stretched over the entire length. The whole runway framed by stripes equal in width to those marking the central part.

Advantages:

Increased visibility due to larger size of markings, increased warning effect, increased emphasis of longitudinal direction.

Disadvantages:

Decrease of perspicuity and clearness, requires more effort and expenses in construction and maintenance.

Sample 3:

Six individual markings, of large size, per outer third, alignment, arranged in three groups of 1, 2, 3 respectively, upon approaching the central part. Other features similar to sample no. 2.

Advantages:

Strong emphasis of outer thirds as compared to central part by stronger charge. Good visibility, especially from high altitudes and great distances. Good perspicuity.

Disadvantages:

Perceptibility of individual markings as units from small distances and slant angles rather questionable. Involves high costs and more efforts in construction and maintenance.

Various combinations of the elementary parts given in the three samples may be feasible by interchanging the central parts of the runways.

II <u>A Study of Runway Markings, Report 2</u>

In "A Study of Runway Markings, Report 1," it was shown that the marking having the shape of a 60 degree chevron proved to be the best of eight tested. In this second part of the project two more detailed questions concerning the chevron in particular were studied.

1. A study was made of the influence of the angle of the chevron on the efficiency of the marking. The chevron element being the most suitable for our purposes, was studied to determine the effect of variation of its angle. Seven different angles were tested, namely, 30, 45, 60, 75, 90, 120 and 150 degrees. They were tested by means of the fog simulator by virtually the same method described in detail in the report of the first part of the project. Ten test subjects were used. The numerical results of this experiment were reduced to the scale of the corresponding table in the Report 1. They are given in Table 1. This reduction was necessary since the measuring range of the fog simulator permits use of the standard size targets (187.5 square mm) as was done in the preceding experiments. This time we used a standard area of 144 square mm. The values obtained for the 60 degree chevron with both experiments were used as a guide for the reduction.

Table I

Angle of Chevron	Elevations
30°	32.8
45°	66.1
60°	64.9
75°	67.7
90°	76.3
120°	66.3
150°	64.1

The results show that the chevron of 90 degrees has an efficiency about 12.6% higher than that of the 60 degree chevron.

2. The markings studied in these experiments were viewed vertically, or almost so. In practical use, however, the pilot of a landing aircraft views the marking pattern under a rather small angle (about 3°). Thus the elements of the pattern are subject to a rather pronounced distortion due to perspective. The angle a chevron must have on the runway in order to produce a retinal image of 60° in the pilot's eye can be easily computed; the result is $3^\circ 40'$. This rather small angle shows distinctly to what an extent man is capable of eliminating subconsciously the distortion due to perspective. This psychological effect was made the subject of a study in order to determine it quantitatively. A white table ($2\frac{1}{2}'$ by $6'$) was constructed carrying two black bars made out of thin sheet metal, hinged together at one end. The bars thus formed an angle which could be

changed, by turning a crank, between the limits of 0 and 180 degrees. The exact angle formed by the two bars could be read on a scale. Both ends of the bar were rounded in order to avoid the appearance of any other angles within the entire pattern of bars and table edges. In the experiment a paper model of an angle of exactly 60° equal in size to the metal bar pair was presented to the test subject. Viewing the table vertically the test subject had to form an angle of 60° by free judgment with the paper angle as model. The examiner changed the moveable angle according to instructions of the test subject. This was done in order to avoid any indication as to the size of the angle from the position of the crank. This procedure was repeated five times, five more results were obtained without assistance of the paper model. The mean of these ten readings was considered as the subject's concept of an angle of 60° comprising the subject's ability in judgment and visualization. An angle of 60° was used instead of an angle of 90°, though the latter proved to be best for the elementary runway marking. The right angle, however, is a very specialized one involving specific psychological characteristics, which make it unsuitable for this experiment.

The subject was then placed at a distance of 16 feet from the table, his eyes being above the extended plane of the table at such an elevation that a viewing angle of 3 degrees was formed. Twenty more settings of the changeable angle, according to the subject's instruction were made. The mean of these twenty settings were related to the subject's personal "60° angle" obtained in the ten foregoing determinations. The difference of the two means served as a measure of the subject's ability to take into account the effect of perspective distortion on the appearance of the chevron. Twenty-two subjects took part in the study. The 660 results were averaged and yielded the result that an angle of 56° 24' viewed at an angle of 3° is taken as an angle of 60°. This rather instructive result shows that the effect of perspective distortion is negligible in the use of the chevron as a runway marking.

As a result of these studies, which are considered to be complete, the 90° chevron was selected as the basic element of a runway marking pattern. Such a pattern has been designed and agreed upon in cooperation with the staff of the Landing Aids Experiment Station in Arcata, California. Figure 1 shows a design of the SAM Runway Marking Plan. This plan is being painted on the Arcata runway and made subject to actual test flights during this year's fog season.

Summary - Two supplementary experiments in connection with the chevron runway marking (the most efficient one according to Report 1 of the study) were made. (1) Seven chevrons differing as to their angle (30, 45, 60, 75, 90, 120 and 150 degrees) were studied by means of the fog simulator. The result was that the chevron of 90° proved to be the most efficient one. (2) The effect of perspective distortion on the appearance of the chevron marking was studied in view of the fact that the pilot of a landing aircraft views the marking pattern on the runway at a rather small angle (3°). A changeable angle was constructed and mounted on a table; in the test procedure it was viewed by the test subject at an angle of 3°. Twenty test subjects made twenty settings each yielding the instructive result that perspective distortion is almost entirely overcome by man's ability to account for it during the process of seeing and its mental evaluation.

A Runway Marking Plan of the School of Aviation Medicine was designed and submitted to the Landing Aids Experiment Station, Arcata, California, where it was installed to be made subject to actual test flights during the current fog season.

III. A Proposed Runway Identification Lighting System

Runway lighting systems presently in use consist of parallel rows of point sources of light running on either side of the runway. The beginning of the runway is indicated by two colored lights, while the end is marked by a row of green lights running across. At times the runway itself is illuminated by floodlights. This system is insufficient in some respects, especially under bad weather conditions. Various improvements have been proposed, some are presently under test at the Landing Aids Experiment Station, Arcata, California. Those improvements concern chiefly the color and intensity of the lights and the spread and direction of the beam.

In view of the results of a study on Runway Markings, Reports 1 and 2, a proposed Runway Identification Lighting System has been designed. In this system it was decided to deviate drastically from the conventional airdrome lighting policy using lights as indicators for the position of the runway. A lamp was constructed with a horizontal plane area of about one square foot which would permit the construction of a large luminous area composed of a large number of these lamps as units. The basic idea of this design was the desire to incorporate into the daylight marking pattern the proposed lighting system. In short, the runway marking pattern described in the two foregoing Reports would be converted into a luminous one by use of these lamps sunk flush into the runway. The aircraft are supposed to land on the lamps.

The lamp which could be utilized for this purpose consists of a heavy glass brick (plexiglas in the models shown), plane on the upper surface and bearing a system of prisms on the lower surface with their faces alternately covered with plastic color filters of two different colors. A ground glass sheet is placed between the glass brick and the light sources consisting of four conventional G.E. fluorescent lamps. The prismatic design has been applied so that light of one color (green) is emitted exclusively in one direction. Light of another color (red) is emitted toward the other side. The horizontal spread of the beam on both sides covers an angle of about 90° with the major axis of the lamp as bisector. The vertical intensity in the plane of the major axis of the lamp covers an angle of about 85° on either side of the lamp. There is a gap of about 5° width at both sides of the vertical plane perpendicular to the major axis of the lamp. This gap separates the green and the red light beams emitted by the lamp. Light is still emitted horizontally at a grazing angle at both sides of the lamp.

A total of 192 lamps of this kind would be necessary to compose one chevron of the standard size. The major axis of the lamps would be parallel to the runway and arranged in such a way that green light would be emitted outward at either end of the runway and red light would be emitted toward the center of the runway. A pilot of an aircraft landing from either end would be guided close to the runway by the approach light system and would be able to identify the proper runway portion by the color of the chevrons.

The advantages of the system are as follows:

1. The pilot can land on a luminous surface indicating exactly where to land, while with present lighting systems the position of the runway is indicated only indirectly. Here, the pilot can approach the lights to the very last completion of the touchdown. This latter fact is of large importance psychologically.

2. The system establishes a means whereby identification of the first, middle and last portion of the runway can be made without error. A heavy load of green light is put on the touchdown area of the runway, and a strong warning is exercised by the red chevrons in the last 1,500 feet of the runway.

3. The horizontal and vertical distribution of light assures visibility of the chevrons from all angles of importance to the pilot.

4. The surface brightness is almost independent of the angle of view and of distance. This secures good visibility and avoidance of glare.

5. Identity of size and shape of the lighting system and the daylight pattern form a substantial help for the pilot in orienting himself with respect to altitude and distance from the runway.

6. The lighting system, by making parts of the runway self-luminous provides good visibility through fog where other illuminants would obstruct the illuminated runway by scattered light.

7. The airdrome is easily identified from great distances in clear weather, since the lighting system is rather conspicuous due to its arrangement. Furthermore, the luminous surface could scarcely be confused with the pointlike lights of city lamps.

The cost of construction and installation, however, of this type of runway markings would be considerable. On the other hand, such an investment may well be justified in view of the advantages of the system.

The lamp can be constructed so that light of a third color (yellow) is emitted toward both sides along the minor axis. For this purpose other prism faces must be added and covered with yellow filters. By varying the area of the prism faces, any ratio of the light thrown along the two axes can be achieved. In a model shown, one-fourth of the light emitted along the major axis is radiated as yellow light along the minor axis, one-eighth of it to either side. The lamps appear yellow as seen from a greater lateral distance. Lamps of this kind could be utilized to outline the chevrons, thus showing a yellow frame around the otherwise dark chevron as seen from the sides of the runway.

Summary

A Runway Identification Lighting System has been designed to convert the daylight marking previously described into a self-luminous pattern. A flat top lamp, about 1 square foot large, was constructed emitting green light to one side and red light to the other. It is planned that the basic elements of the marking pattern, the chevrons, be composed of 192 such lamps sunk into the runway so that aircraft can land on the lamps. The lamps are arranged in such a manner that the first portion of the runway appears covered with green chevrons, while the chevrons on the last 1,500 foot stretch are red. This holds true as seen from either end of the runway. Advantages of this system of runway identification lighting are discussed.

DISCUSSION:

Mr. Breckenridge told the group of his recent visit to the Landing Aids Experimental Station at Arcata, Califirnia, where extensive tests are being made of identification systems to aid in landing aircraft. He expressed his belief that the angular subtense of patterns which are capable of assisting pilots in landing aircraft under fog conditions is extremely small, and that application of the Haber tests to fog conditions was therefore not certain. Mr. Breckenridge stated further that he was convinced that pilots do not examine the landing strip at the angle Dr. Haber utilized for his tests. He stated that instead, because the pilot cannot see the ground, a 15 or 20 degree angle rather than the 3 degree angle Dr. Haber expected is utilized.

Mr. Breckenridge also expressed his belief that the device Dr. Haber had developed as a landing aid would not stand practical use because of sand and tire wear on the exposed glass surface.

Dr. Haber stated that tests had been made with his device in which ground glass was placed on the surface of the device, this representing the worst possible case of sand and tire wear. He stated that even under these circumstances, the device continued to perform as well as before.

Dr. Blackwell criticized the logic of the experiments performed. The principle involved is that perceptual equivalence of two stimulus patterns does not imply "physiological" equivalence. As an example of this idea, Dr. Blackwell reported that it was well-known that in spite of the effect called size constancy, sensitivity of the eye to simple stimulus patterns at various distances depends upon the visual angle rather than the perceived size. With reference to the Haber experiment, Dr. Blackwell then made the parallel: Dr. Haber first showed that a chevron of given angular characteristics had the greatest "resistance" to blurring and to contrast reduction. Then Dr. Haber showed nearly complete shape constancy, indicating that a chevron pattern whose angular separation on the retina was only 3 degrees 40 minutes, had an apparent angular separation of 56 degrees, where 59 degrees 45 minutes was complete constancy. Dr. Haber then assumed that the effect of an actual 3 degree 40 minute stimulus pattern was optimal in terms of "resistance" to blurring and to contrast reduction.

Dr. Blackwell also questioned the use of ground glass to simulate the atmospheric effect. He stated that the ground glass has two effects, those of blurring the image and of reducing its contrast. Apparently in the atmosphere these effects are not necessarily related, whereas in the ground glass they bear a very special relationship to each other.

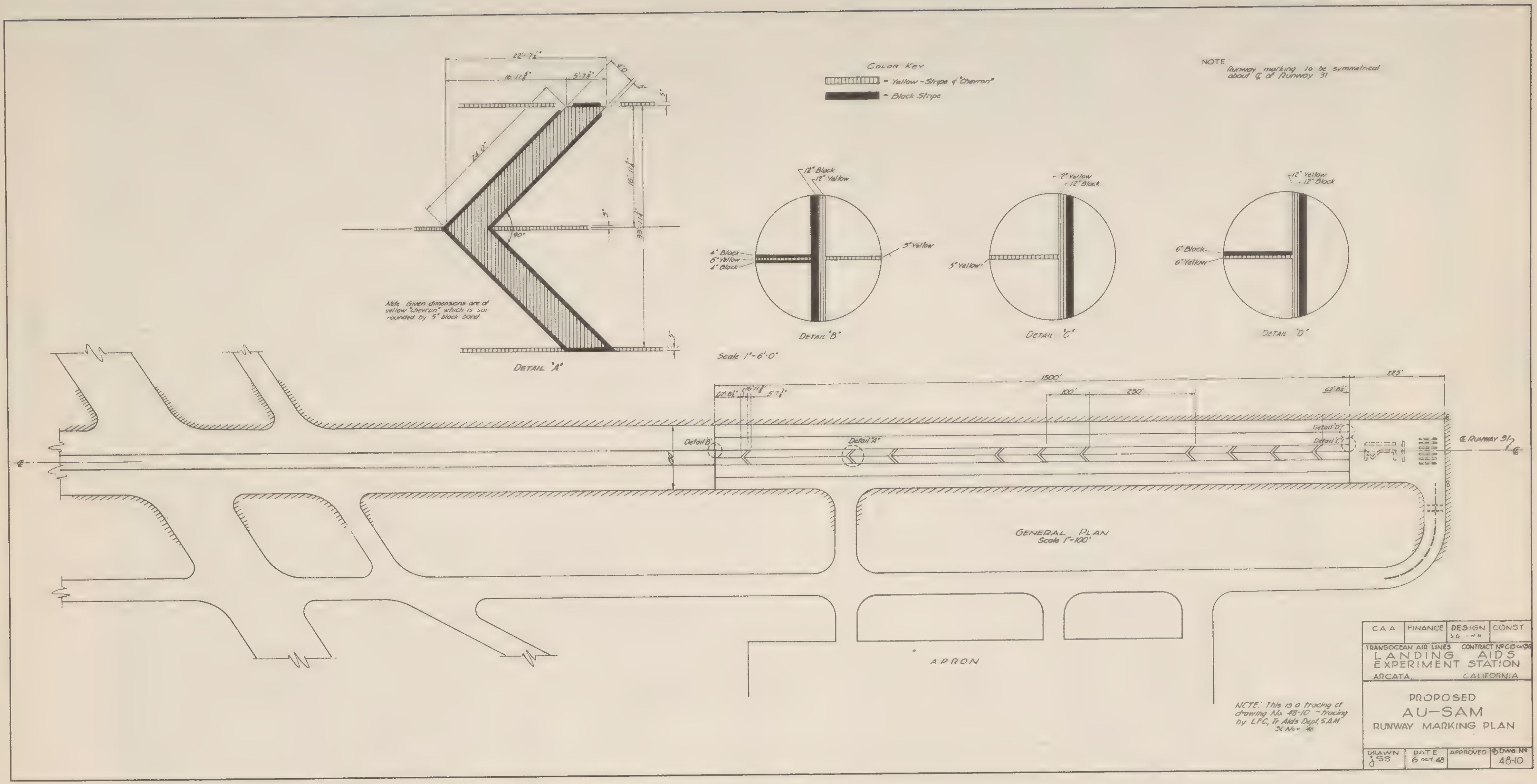
Dr. Blackwell made the point that the detectability of a blurred stimulus depends upon its size, whereas the effect of contrast reduction is independent of size. Dr. Blackwell suggested that in Dr. Haber's experiments the effects of blurring and contrast reduction should have been kept separate. He suggested that a contrast reduction meter, such as that developed by O'Brien, could have been utilized without introducing blurring effects at the same time.

Dr. Duntley made a series of remarks which he has kindly summarized as follows:

> "Theoretical and experimental studies by several investigators during the past few years make it appear certain that the ground glass plate effect does not exist under ordinary circumstances. The case of fogs containing very large water particles or very large ice crystals has not yet been satisfactorily explored and although it is not expected that a ground glass effect will be observed, we should not at this time be dogmatic about it. It is definitely not true that a ground glass produces the same optical action as the atmosphere. Dr. Haber may, however, have been justified in using a ground glass as an "atmosphere simulator" in the same sense that a landscape painter is justified in using blurred outlines to simulate effects that occur in his eye as he views a scene in which haze or fog reduces contrast to the point where small objects are below threshold. Dr. Haber's quantitative results are of very doubtful validity because his simulator is wrong in principle, but since he used his data only to select the best of several patterns, his selection may have been correct. From this standpoint he may have been justified in using a ground glass."

Dr. Duntley also mentioned a method of applying paint which leads to directional spectral characteristics very similar to those possessed by Dr. Haber's landing aids device. The painted surface produced by this technique looks blue from one angle, and red from another. Dr. Duntley wondered whether this principle might not prove useful to Dr. Haber in connection with this type landing aid.

Dr. Hulburt agreed with Dr. Duntley that we do not know whether the exact edge of an object is blurred by the atmosphere, but emphasized that the existence of an illuminated aura about a light at night, for example, represented a case not too dissimilar from that utilized by Dr. Haber in his experiment. Dr. Hulburt agreed that we do not have sufficient evidence to predict the effects of this aura around lights upon human vision.


COLOR KEY
= Yellow - Stripe & "Chevron"
= Black Stripe
NOTE: Runway marking to be symmetrical about ℄ of Runway 31
Note: Given dimensions are of yellow "chevron" which is surrounded by 5" black band
DETAIL "A"
DETAIL "B"
DETAIL "C"
DETAIL "D"
12" Black
12" Yellow
4" Black
6" Yellow
4" Black
5" Yellow
6" Black
6" Yellow
Scale 1"=6'-0"
1500'
225'
100'
250'
GENERAL PLAN
Scale 1"=100'
APRON
℄ Runway 31
NOTE: This is a tracing of drawing No. 48-10 - tracing by LFC, Tr Aids Dept, S.A.M.
CAA
FINANCE
DESIGN
SG - HH
CONST
TRANSOCEAN AIR LINES
LANDING AIDS
EXPERIMENT STATION
ARCATA, CALIFORNIA
PROPOSED
AU-SAM
RUNWAY MARKING PLAN
DRAWN
DATE
6 OCT 48
APPROVED
DWG No
48-10

THE TWO SIDES OF THE PHYSIOLOGICAL EFFECT OF INTERMITTENT LIGHT

by
H. Strughold

If we investigate an object or an effect for its usefulness, we almost always find two sides, a harmful and a useful one, comparable to the doublefaced Janus of ancient Rome. This rule holds for intermittent light to a particularly high degree. I am going to begin with its harmful side.

About 15 years ago I had some indoctrination films shown in my physiology lecture. At the end of the films, when the projector was running empty, I sometimes looked into the light source and noticed an extremely strong, disturbing effect of this intermittent light on the eye. Years later when it was repeatedly reported that flyers felt extremely handicapped by searchlights through which they flew, I recalled the observation I had formerly made on intermittent light. In collaboration with Dr. Ingeborg Schmidt I started investigations to find out at which frequency and intensity the disturbing effect was greatest. We used a motor driven, adjustable episcotister and a light intensity of 200 HK (35 Lambert) of the constant light in a distance of 5 ft. The test subjects were required to indicate the subjective effect in three different grades of tolerance: bearable, disagreeable, and very disagreeable.

We found on all subjects (10) that the frequency ranging between 3 and 5 cycles per sec produces a particularly unpleasant sensation. (See Table 1.)

TABLE 1

Frequency of 1 cycle per second - bearable to disagreeable
Frequency of 2 cycles per second - disagreeable
Frequency of 3 cycles per second - very disagreeable
Frequency of 4 cycles per second - very disagreeable
Frequency of 5 cycles per second - very disagreeable
Frequency of 6 cycles per second - very disagreeable to disagreeable
Frequency of 7 cycles per second - disagreeable
Frequency of 8 cycles per second - disagreeable
Frequency of 9 cycles per second - disagreeable
Frequency of 10 cycles per second and more - improvingly bearable
Exceeding to fusion-frequency - bearable

Above and below this frequency range the tolerance improved to an increasing extent. The characteristic sensation at frequencies below 6 cycles is the alternation between light and dark. Not only the light stimulus, but also the sensation of light is intermittent, which means interrupted by short intervals of the sensation of darkness. With intermittent light stimuli above 5 cycles per second, however, the sensation is that of constant light which alternates in intensity. So we have in the first case intermittent light stimulus and intermittent sensation of light and in the second case intermittent light stimulus but remittent sensation of light, i.e., a continuous sensation of light which decreases periodically. To characterize this difference from a physiological point of view we must perhaps coin a new word. The German terminology provides an adequate description by the words "Flackerlicht," which means flicker light and "Flimmerlicht" or flimmer light. I would like to recommend that the English term flicker light be used only for intermittent light of low frequency and flimmer light (or a similar term) only for higher frequencies

close to the critical fusion frequencies. (See Figure 1.) This discrimination is necessary, at least from the physiological point of view. In addition to these kinds of intermittent light, we know the internationally defined blink light--intermittent light with very low frequency. Whatever terms may be used, it is the flicker light with intermittent light sensation which produces the greatest disturbing effect.

The prerequisite for the disturbing effect is a certain light intensity, not below 150 to 200 HK (30-35 Lambert) of the constant light in a distance of 5 ft.

Now, what is the nature of the disturbances? There are disturbances of sensoric and reflectoric nature. Apart from a certain glare effect, we have the inpression that we are flooded by a series of halations with intermediate dark phases, which seem to propagate like waves after a stone has been dropped in the water. In short, the effect is one of optical confusion. The estimation of the distance from the light source is almost impossible. Also nausea-like symptoms can be observed. The mechanism of the disturbance may be explained in the following way: The reaction time of the pupil is about two-tenth of a second. If the light interval is greater than the reaction time, the pupil responds just slightly to each incoming light stimulus. With the magnifying glass one can actually observe a mild tremor of the pupil. This rhythmical hammering on the autonomic nervous system through the pupillary reflex may be a reason for the unpleasant sensation produced by flicker light at frequencies below 6 cycles per second. Yet, this disturbing effect of the pupillary reflex is only a secondary phenomenon. The predominant impression refers to the sensorial part of the eye. The disagreeable intensity of the sensation of flicker light or of the intermittent light sensation may perhaps be explained with the Weber's Law, which states that the added intensity necessary to cause a just perceptible difference in sensation bears a constant ratio to the preceding intensity. The light flash can be regarded as an additional stimulus increasing the intensity of the basic stimulus which acts upon the retina during the intervals. The intensity of the basic stimulus is very low during the intervals of darkness of the flicker light. The subsequent light flash produces a very great difference between the intensity of the additional stimulus and that of the basic stimulus. The light flash, therefore, creates an extremely intense and disturbing sensation. In the frequency range of the flimmer light each individual light stimulus is set up before the sensation evoked by the preceding stimulus has passed off. Thus each subsequent light stimulus means only a slight increase in the original stimulus. Therefore, flimmer light or remittent light sensation is bearable. This is one explanation given from the viewpoint of the physiology of the senses.

Another explanation is based on the electrophysiological behavior of the organ of light perception with regard to intermittent light. Whereas research work on the electroretinogram and electroopticogram is still in the initial stage with regard to intermittent light, studies on the electroencephalogram are more advanced. According to investigations made by G. H. Bishop and T. S. O'Leary, Kornmueller and Noell, the EEG shows changes in the alpha waves. These waves become spiked, especially when the frequency of the stimulus is a half, a third or a fourth of the frequency of the alpha waves. (Figure 2) Whether this phenomenon represents a kind of "photoelectrophysiological resonance," or whether in these cases the excitability of the central optical system is optimum remains an open question. The electroencephalogram resembles greatly that recorded in cases of epilepsy. In fact, Bickfield, co-worker of E. G. Baldes, Rochester, Minnesota, was able to produce epileptoid fits experimentally by intermittent

light. This phenomenon, which is likely to become of great diagnostic value, is designated by the authors as "photoepilepsy."

G. Prast directed attention to the following comparison: As it is generally known in severe oxygen deficiency, shortly before convulsions set in, the frequency of the alpha waves decrease from the normal 10 down to 6, 3 and 2 cycles per second. This stage is characterized by severe numbness of the test subjects. Upon exposure to flicker light of 3 to 5 cycles per second in normal air, a similar frequency is super-imposed upon the electroencephalogram, which might produce the confusion above described. In this connection it is of interest that the imposition of slowly changing electrical currents on the brain from outside produces a similar state as experienced during slow waves. W. Grey Walter found that when a current of about 20 milliamps, fluctuating at one or two cycles per second, is passed through the head by means of electrodes, a "drowsy and unattentive state of mind" can be induced. Whatever the correct explanation may be, flicker light has a strong disturbing effect and this disturbance occurs especially at frequencies ranging between 3 and 5 cycles per second.

It is obvious that flicker light represents an excellent protective weapon. The individual exposed to the flicker light is handicapped for some ten seconds, whereas the vision of the person manipulating it, is not impaired. So much for the disturbing effect of intermittent light.

Let us now look at the other side of the problem! We start from well known observations:

1. If we fixate a certain colored point on a colored wallpaper pattern the sensation of color disappears after about 6 seconds except for the point fixated. Movement of the eyes or a blink reflex restores immediately the sensation of color for the whole pattern.

2. We fixate one star of medium brightness on a dark sky. After 6 seconds we see nothing but this single star against the black sky. Fixation movement of the eyes or a blink reflex makes the entire star-lit sky instantaneously reappear before our eyes.

This disappearance of objects from the visual field, except those in the direct line of vision, is known as fixation amaurosis. This phenomenon is based on the so-called local adaptation of the retina.

Local adaptation of the retina has been known since the times of Troxler (1809), Aubert (1865), Brewster, Purkinje, and Hering. During the last ten years it has been studied more thoroughly by Cibis. He found that a red object at an angle of 10° to the fovea loses its red appearance after 4 seconds, at an angle of 20° after 2 seconds, etc. Similar observations were made with yellow and green objects, etc.

Formerly, V. Hess obtained the following results: A red spot of 2 mm diameter at a distance of 30 cm disappeared at an eccentricity of 5° after 10 seconds. It disappeared at an eccentricity of 7° after 6 to 7 seconds, at an eccentricity of 9° after 4 to 5 seconds and at an eccentricity of 11° after 2 to 3 seconds.

The most essential characteristics of local adaptation can be summarized as follows:

1. When we look at a colored object continuously for a prolonged period of time, especially when the view is indirect, first the perception of the color of the object and later the perception of the object itself disappears. The former stage is called specific local adaptation, the latter, general local adaptation. Cibis called it the "specific niveau effect" and "general niveau effect," respectively.

2. Local adaptation, especially with regard to colors, is effected rapidly in extra-foveal vision, but rather slowly in central vision. The velocity increases with the eccentricity.

3. Local adaptation is eliminated:

   a. By movement of the object.
   b. By exposing different retinal regions through interfixational movement.
   c. By interrupting the stimulation of the retina for short periods of time by means of the blink reflex.

The duration of fixation normally varies between 70 and 300 milliseconds. The interfixational movement lasts from 30 to 100 milliseconds. The blink reflex occurs about every 3 to 6 seconds. It takes the eyelid about 30 to 40 milliseconds to cover the pupil completely; the total eyelid reflex including the accompanying slight eye movement and re-fixation lasts one-tenth of a second. Fixation movement and blink reflex are obviously the natural mechanisms to effect the elimination of local adaptation. Their duration is apparently sufficient to eliminate the traces of any local adaptation. Interfixation movements seem to do away with mild adaptation, whereas the blink reflex eliminates local adaptations on a larger scale by giving the retina time to recover during one-twentieth of a second of non-exposure. This function of the blink reflex seems to be not less important than its task of moistening the eye.

As we can see from the experiments on local adaptations, which I have mentioned before, we perceive the total visual field very clearly only in the first second, then the objects in the visual field start to fade from the periphery towards the center in rather short time. It might be of interest that some findings in the Electroencephalogram as is shown in Figure 3 (according to J. Prast and Frantek) might have some relation to local adaptation. Trying to avoid this phenomenon, we are very likely to think of imitating the example given by nature, namely, the blink reflex. This can be done by intermittent exposure. That means by interrupting the exposure to light about 1 to 2 seconds by a dark phase lasting one-tenth of a second. I think that this is especially useful when we must look at an object continuously as is often the case with scientific instruments. In this connection I think of an intermittence colorimeter, intermittence perimeter, intermittence anomaloscope, etc. The latter is already in use by Dr. I. Schmidt. In particular the determination of color thresholds on the retinal periphery by means of Haber's thresholdmeter requires intermittent stimulation to avoid a "stealing in" of the subthreshold stimulus. With regard to this phenomenon the observation of a Dutch painter might be interesting. When he painted a windmill and the surrounding countryside, the scenery behind the rotating blades appeared to him richer in color than did the rest of the landscape. Incidentally, a similar effect is obtained by the windshield wiper of a car.

Recently R. D. Lowson reported that the blink reflex was a considerable source of error in counting processes such as scintillations in nuclear physics, since the observation would be interrupted for one-tenth of a second and the number of blink reflexes per minute would vary considerably. In this case the errors might be reduced by introducing an artificial blink reflex which has a constant duration of 1/20 sec and occurs at constant intervals of 2 seconds.

The importance of an intermittence of all optical warning signals, especially of those in the instrument panel, need not be emphasized in particular.

Also intermittence of higher frequency, which would correspond to "flimmer light," might improve vision particularly by the sharpening of contrasts. According to many observations during the last years, I consider this important in the observation of microscopic pictures, astronomic photographs, and pictures of processes dealing with nuclear physics. Only an observation in constant <u>and</u> intermittent light will be, in many cases, a complete one, for in intermittent light we observe things which we fail to see in constant light and vice versa. Intermittent light even enables us to perceive entoptic phenomena such as the fovea using blue intermittent light. Incidentally, intermittent observation also produces a stereoscopic effect. I suppose that this has to do with the latent time of perception which depends on the intensity and color of the stimulus and on the region of the retina. As yet I cannot give details in this respect since the experiments are still in process.

Once the famous astronomer Herschel, who had developed a number of important optical instruments, said "Vision is an art." I believe that the application of the <u>principle of intermittent light</u> is a remarkable aid to refine this art.

* * * * * * * * * * * * * * * * * *

1. Aubert, H. Physiologie der Netzhaut. 1865.

2. Bishop, G. H. and Leary, J. S. O., Journal of Neurology, 1940, p. 315.

3. Cibis, P. Arch. F. Ophthal. 148, 1, 1947: 148-216, 1948.

4. Hess, C. v. Arch. Augenheilk, 1919, 25, 327.

5. Lowson, R. W. Nature, 1948 Jan. 31.

6. Prast, J. and Frantek, Br. Z. f. Naturforschung, 1946 I, 291.

7. Strughold, H., Intermittent light, Monography of German Aviation Medicine 1949.

8. Gray, Walter W., Proceedings of the Royal Society of Med., Vol 1948 XLI, 237.

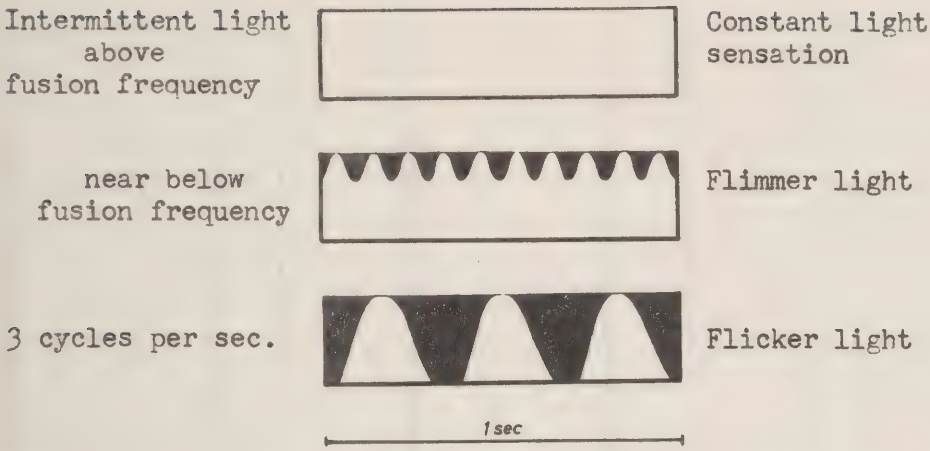


Figure 1

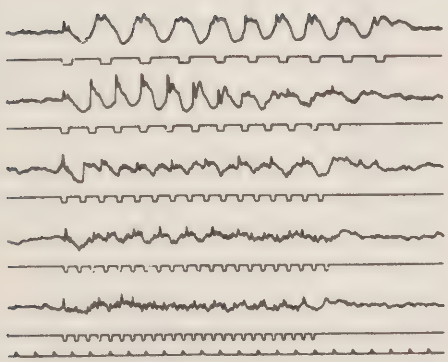


Figure 2

Unipolar lead from the surface of the area striata of a rabbit during exposure of the eyes to rhythmical light of various flicker frequencies. The stimuli are recorded under the brain potential curve. At the flicker frequency, as shown in the top two curves, the effect on the action current is the greatest (test by A. E. Kornmueller and W. Noell).

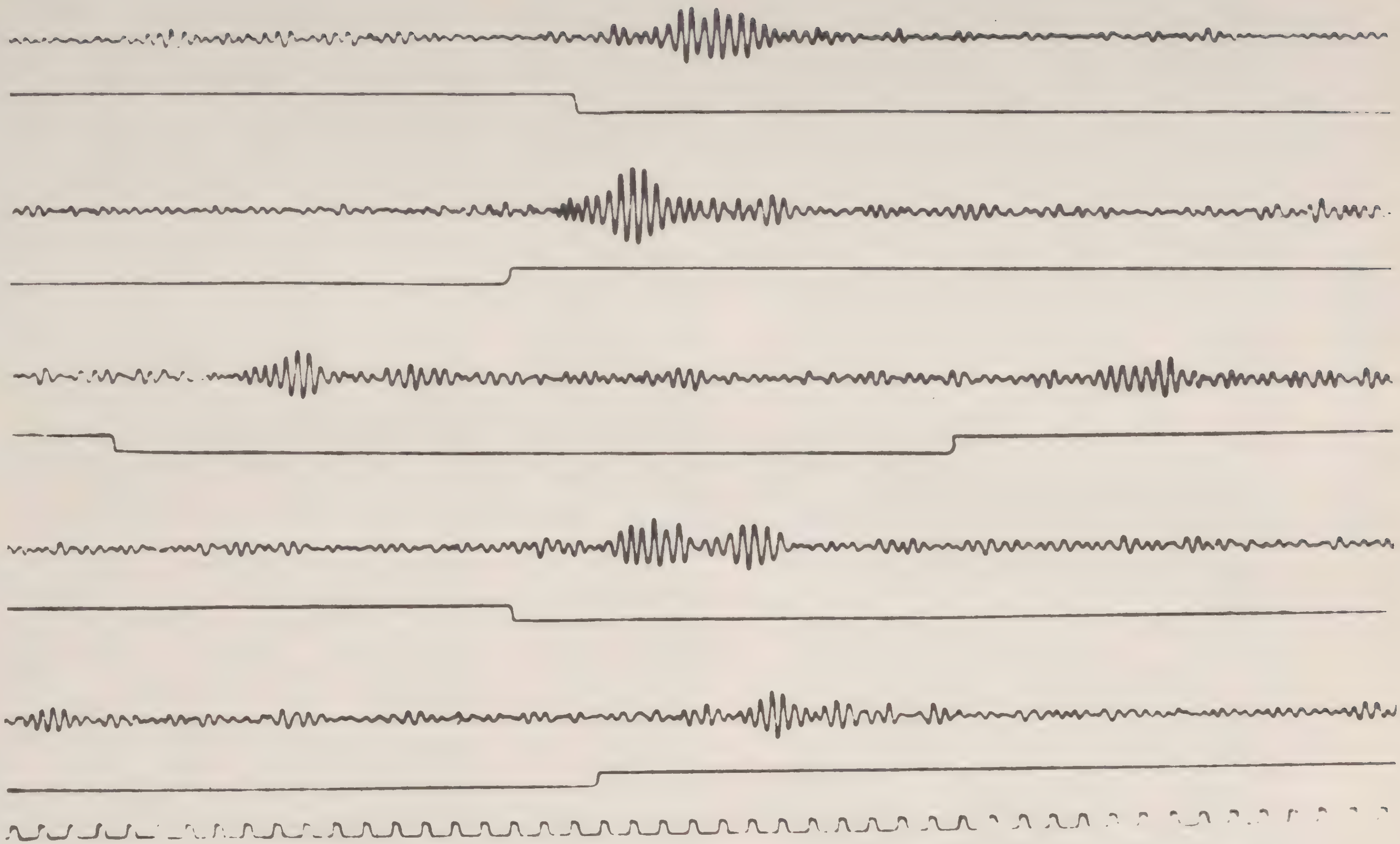


Figure 3 Filtered alpha waves of the brain during strong illumination of the eye. Line of stimulation shifting down means beginning, shifting upwards means the end of the illumination (by Prast and Frantek).

ANOXIC EFFECTS ON THE OPTIC PATHWAY

Werner Noell and Herman Chinn
School of Aviation Medicine
Randolph Field, Texas

The effect of anoxia on the brain may be considered as an action exerted on a population of ganglion cells which differ in their susceptibility, depending upon their location in the brain. This population is characterized further by the ability of each of its units to influence other units, which ability varies with the architecture of the different portions of the brain. Thus the anoxic failure of one neuron might change the activity of other neurons which otherwise would show a lesser anoxic effect at that stage. Such complex relationships are beautifully illustrated by the optic system. Judging from well-known phenomena, two different portions of this system — the cortex and the retina — compete for anoxic failure of vision. When g forces are rapidly applied, the retinal component of the optic system has been shown to be responsible for the resulting "blackout"[1]. However, when the blood is rapidly freed of oxygen, as in explosive decompression, cortical sentivity is the dominating factor and sudden unconsciousness ensues with no preceding disturbances. In addition to these two clear-cut actions upon the retina and cortex respectively, a combined failure of both these portions of the optic system is thought to be responsible for the visual disturbances in hypoxia. The experiments to be reported here have been done on the optic pathways of the rabbit. For anatomical reasons, these afford a relatively easy approach to the problem of anoxic sensitivity of different parts of the brain.

The bioelectrical responses of the optic system to photic stimulation were recorded, as well as the response to electrical stimulation of the various points between the receptors and the cortex. The procedure necessitated only local anesthesia so that anoxia could be studied on otherwise normal animals. For the cortical potential, small screws, which served as electrodes, were inserted into the skull without injury to the brain tissue. Intermittent stimuli at second intervals were applied either to the eye or to the optic nerve.

As may be seen by Figure 1, the electrical response from the visual cortex to a flash of light into the contralateral eye consisted primarily of a small, brief surface positive deflection, either single or multipeaked. According to Bishop, Bartley and O'Leary,[2, 3] this deflection represents essentially the intracortical spread of excitation to the impulse travelling along the optic pathway. The deflection was followed by large, slow waves which might also appear spontaneously without specific stimulation of the eye. Anoxic changes of this response became evident 12 to 13 seconds following administration of nitrogen. All components of the response increased in magnitude. Large, spontaneous waves either appeared or increased in amount, so as to occupy the interval between the stimuli. This activity was short-lived and, within 4 to 6 seconds, all spontaneous waves ceased. The response to the light stimulus persisted and developed upon the nearly silent base line. Its configuration had changed, however, to a nearly monophasic deflection with a considerably higher amplitude and longer duration than the corresponding deflection in the normal response. The decline of this deflection to a low amplitude was surprisingly slow, requiring 50 to 80 seconds (average 66). An additional 20 or more seconds were required for the disappearance of all detectable responses. Thus, the survival of the cortex, as measured by the time for complete irresponsiveness to sensory stimulation, is much longer than is generally realized. This becomes more

apparent when the timing of other anoxic events is given.

Anoxic convulsions generally appeared after 16.5 seconds of nitrogen breathing, and persisted until the 35th second. From our knowledge with humans, unconsciousness should result at or before the onset of convulsions. Rhythmic respiration ceased after 29 seconds and bradycardia was most marked by the 26th to 40th second. However, other gross manifestations of central nervous activity survived much longer than the cortex. Gasping persisted, in many cases, for over 2 minutes. Normal vasomotor activity was also evident as shown by the maintenance of blood pressure which did not drop below the original level until the cortical responses had already fallen to low amplitude. These data suggest that the resistance of brain functions to anoxia depends not only upon the gross structure with which the function is associated, but also upon the neurophysiological construction of that function. In other words, the more complex and delicate is the function, the more apt is it to fail early in anoxia.

The simplified response potential obtained in the later phases of anoxia offered a convenient method of analysis, using the amplitude of the potential as a measurement of the anoxic effect. The decline of the response potentials from their highest values during early anoxia was influenced in a characteristic manner by changes in the frequency and intensity of stimulation. Figure 2 indicates the effect of the former factor. The optic nerve was stimulated electrically (condensor discharge) at intervals from 1 to 4 seconds between successive stimuli. As can be seen, the longer was this interval the higher was the corresponding response. Furthermore, the rate of the response decline was slowest with the longest intervals between stimuli. Consequently, the time necessary for recovery from excitation during anoxia was probably in excess of 4 seconds. This effect was accentuated when higher stimulating frequencies were used. As indicated by Figure 3, the optic nerve was stimulated by trains of 5 per second condensor discharges alternating with a single shock of 4 seconds after the end of train and 2 seconds before the next train. With each successive stimulus during a single train, the response dropped until minimal amplitudes were reached. However, during the 4 seconds rest interval following the train of stimuli, there was sufficient recovery to permit again the production of high amplitude responses despite the continuing anoxia. Thus, with repetitive excitation, the process of recovery became progressively less adequate to restore excitability when the interval between excitation was shorter than the time necessary for complete recovery. If the rate of restoration be considered as roughly constant, the depletion of a basic "energy store" must be assumed to progress with repetitive excitation under these conditions.

In general, therefore, our results were similar to those of Bronk and coworkers[4] who stated that the intrinsic energy supply of the stellate ganglion during anoxia was more rapidly depleted with repetitive activity. In this connection, it may be pointed out that one sign of insufficient recovery between 2 stimuli was an alternation in the magnitude of response when the same stimulus frequency was maintained. This was especially obvious when stimuli were applied at a rate of 2 per second, but the same pattern was also occasionally noted with 1 per second sequence. Similarly, the interruption of a steady decline of response potential by a constant response amplitude for 2 or 3 stimuli is another manifestation of insufficient recovery from excitation. These phenomena indicate that at the edge of complete irresponsiveness which results from the progressive action of anoxia, one fraction of the cell population may respond with each stimulus, another fraction responds only with every other stimulus, and possibly still other fractions after every 3rd or 4th stimulus, and so forth.

The rate of the response decline was significantly altered when the intensity of stimulation was changed. Figure 4 illustrates the decline during anoxic episodes when successive impulses of standard illumination alternated with lower intensity impulses. The similar results with electrical stimulation of the optic nerve is shown in the next figure (Figure 5). In both instances, the decline curves obtained with different stimulating intensities revealed an approximate parallelity except near the termination of the anoxic episode, when the decrease to low amplitudes had occured. In other words, the effect of anoxia was greater proportionately when the original response amplitudes, due to lower stimulus intensities, were lowest. If the anoxic effect were proportionate to the response amplitude, a steady convergence of the decline curves should result.

As with any peripheral nerve in anoxia, the progressive failure of cortical activity represents a progressive decrease of excitability. Theoretically, the course of this failure, as expressed by the decline of the response potential, should be the resultant of 2 functions: (1) the distribution of the anoxic vulnerability over the neuronal population and (2) the effectiveness of a decreased excitability on differently organized neurons which might be essentially alike in their anoxic resistance and in their excitability. In the latter possibility, it must be remembered that the capacity of any particular neuron to discharge in response to impulses from an afferent tract depends, in addition to its excitable properties, upon the number and timing of impulses which reach its synapse and summate thereon. With a general decrease in excitability those neurons whose induced summation process barely exceeds the threshold of discharge are most apt to be inactivated early. Conversely, the last neurons to be inactivated would be those which can endure a much greater decrease in excitability before the threshold for a given impulse is reached. If it is assumed, therefore, that the intracortical summation occurs under less favorable conditions when the intensity of stimulus to the afferent pathway decreases, then anoxia would be more effective in reducing neuronal excitability. The decline curve of the response potential with a given stimulus intensity should then tend to diverge from a curve obtained with a higher intensity stimulus. The effectiveness of a generally decreased excitability on differently organized neurons is thought, therefore, to be a key factor in determing the progressive failure of a complex neuronal population. The effect of anoxia on neuronal activity might then be essentially the same as that of any depressing agent. Bishop and O'Leary[3] found that increasing the depth of anesthesia decreased the amplitude of late components of the cortical response (spike series) to single stimuli of the optic nerve before it affected the earlier members. The last spike to disappear was from the afferent radiation. Our explanation for the anoxic failure of the cortex agrees fully with their findings and interpretation. A similar process might also operate at the retinal level, which would explain the impairment of vision peripherally during the anoxia of high g forces before any central visual disturbances are apparent. The summative processes at the retinal level are less important centrally than peripherally, because of the known differences in the transmission of excitations from the cones and rods to the final optic nerve axon.

By comparing the response to light stimulation of the eye with that of electrical stimulation of the optic nerve, we attempted to determine to what extent anoxic failure of the retina influences the simultaneous failure of the cortex. With the eyeball held downward, the tissue covering the optic nerve was dissected without injury to the nerve itself. A shortened fine surgical needle was inserted below the optic nerve to serve as a stimulating electrode and a second electrode was placed in the surrounding tissue. The eyeball was

then allowed to return to its original position and the usual experimental procedure initiated. Three electrical shocks at second intervals were applied alternately with 3 photic stimuli to the same eye during the entire anoxic episode. Also in some instances photic stimulation of one eye was compared with electrical stimulation of the contralateral optic nerve and the responses of both areas striata recorded simultaneously. Once the intensity of both stimuli had been so adjusted that the maximal responses during anoxia were approximately equal, the decline curves were almost identical. Figure 6 represents such an experiment. Consequently, any simultaneous effect of anoxia on the retina if present, was generally insufficient to influence the decline of the cortical response.

To gain further information concerning the susceptibility of the retina to anoxia, the potentials from the optic tract were measured simultaneously during anoxia. Either a general anoxia was produced by nitrogen breathing or a local anoxia of the eye was caused by increasing the intraocular pressure to a level in considerable excess of systemic pressure so that a complete cessation of intraocular circulation was insured. First, the duration of optic tract responses to eye illumination was determined under these conditions. The survival of the eye was found to be surprisingly long, exceeding that of the gasping mechanism and of any vasomotor activity. In all of these experiments, complete irresponsiveness of the optic tract occurred so late, that revival of the animal was impossible when resuscitation was attempted at this point. The retinal survival times ranged from 140 to 180 seconds in contrast with the cortical survival time of 50 to 80 seconds during nitrogen breathing. When 1.5% oxygen was breathed, the average cortical survival time was 100 seconds, while the optic tract survived for 255 seconds. With a sudden application of high intraocular pressure, the mean survival at the optic tract level was 173 seconds. In 2 experiments, the circulation of the head was completely interrupted by decapitation. In these instances, the cortical survival times were between 30 and 40 seconds compared with a persistence of optic tract potentials of 170 to 190 seconds. To determine the time course of optic failure to illumination, our procedure was the same as has been described for the cortex. The amplitude of the "on"-potential was measured at the optic tract level and plotted against time. A series of 5 stimuli of 110 milliseconds duration and of increasing intensity were applied at second intervals with an interval of 3 seconds between the 2 series. Figures 7, 8, and 9 illustrate typical examples of these experiments. In a number of cases, the optic tract potentials did not decline until relatively late. However, in other instances the decline began within 20 seconds after complete anoxia, which approached the times observed for the start of cortical decline. Presumably, in these latter cases, the pickup of the potentials was from a smaller number of nerve fibers due to different positioning of the electrode which had been thrust through the brain tissue into the optic tract.

Simultaneous records of the cortex and optic tract potentials during complete arrest of retinal circulation revealed that impulses from the retina might reach the visual cortex as long as any optic tract potentials were detectable. This finding reduces the possibility that those retinal units supplying excitation for the pathway to the visual cortex might be more sensitive than those connected with the midbrain.

Of all the components of the optic tract potentials resulting from illumination, the first waves of the "on"-effect disappeared last. In most cases, the "off"-response of the potential followed a similar course of decline, but was never detected when the "on" response had disappeared for the highest stimulus intensities. In late stages of anoxia, "on" and "off" effects were the only

detectable response to illumination (Figure 10). Other waves which had earlier been present in variable amount had disappeared completely. This is in accordance with the cortical findings that repetitive excitation is much more affected because of a delay of recovery processes, than is a single excitation after a long rest interval. An especially rapid initial decline was found for a wave following the early "on"-response. This wave may be identical with that described by Bartley and Bishop[5] as the "second on-wave". (Figure 11) The decline of this wave to low amplitudes occured in some instances within 20 seconds and the first measurable reduction in amplitude was occasionally noted within 8 seconds after the onset of anoxia.

However, all our findings on optic tract potentials are rather surprising in view of the very early occurence of blackout in human beings. The large temporal difference of these events (blackout versus retinal irresponsiveness) might be interpreted as representing species differences between the retinas of the rabbit and of human beings. If such differences are unlikely, the possibility remains that blackout occurs as soon as a definite pattern of repetitive excitation of the optic pathway is disturbed. Further experiments, employing higher animals, are therefore necessary before these findings can be interpreted.

The last part of the optic pathway to which reference shall be made is the optic nerve itself. This nerve, both structurally and developmentally, represents a fiber tract of the brain. Its anoxic behavior, therefore, might serve as an example for central fibers in general. Survival during sudden and complete anoxia was measured by stimulating the nerve as already described, shortly after it leaves the eye and recording the response potential in the optic tract. Electrical stimulation of the nerve was alternated with photic stimulation of the corresponding eye. A typical experiment of this type is illustrated in Figure 12. The survival time of the nerve is seen to exceed only slightly that of the retina. The mean of our experiments was 210 seconds compared with the mean survival time of the retina of 180 seconds. This figure shows also that the decrease in excitability of the optic nerve fibers follows very closely the decline of retinal excitability. This finding implies that axon and ganglion cells might be essentially alike in their susceptibility to anoxia. Confirmation is thus given to the similar results of Bronk and coworkers[4] on the stellate ganglion of the cat. These workers reported that synaptic transmission may persist as long as conduction for certain nerve fibers. If we apply the conclusions given above to the failure of an interdependent neuronal population, these findings emphasize that excitation over pathways where the ganglion cells and their synapses are simple links in axonal conduction should be much more apt to survive than those neuronal chains in which complex excitatory processes are involved. Thus central vision should survive longer than peripheral vision during retinal anoxia.

BIBLIOGRAPHY

1. Lambert, E. H. and E.H. Wood — Problem of blackout and unconsciousness in aviators — M. Clin. North America 30:833, 1946

2. Bartley, S. H. and G. H. Bishop — Factors determining the form of the electrical response from the optic cortex of the rabbit — Am. J. Physiol. 103:173, 1933

3. Bishop, G. H. and J. O'Leary — Potential records from the optic cortex of the cat — J. Neurophysiol. 1:391, 1938

4. Bronk, D. W., M. G. Larrabee and J. B. Gaylor —— The effects of circulatory arrest and oxygen lack on synaptic transmission in a sympathetic ganglion — J. Cell. and Comp. Physiol. 31:193, 1948

5. Bartley, J. H. and G. H. Bishop —— Some features of optic nerve discharge in rabbit and cat —— J. Cell. and Comp. Physio.. 19:79, 1942

DISCUSSION:

Dr. Marquis asked whether Dr. Noell had considered the possibility that the prior failure of cortical potentials relative to optical nerve potentials under anoxia might be due to the smaller diameter of cortical fibers.

Dr. Noell reported that this possibility had been considered. He stated that although the evidence was not completely convincing, he favored the hypothesis that there is the difference in complexity of innerconnections which leads to the earlier failure of cortical portentials in anoxia.

Figure 1

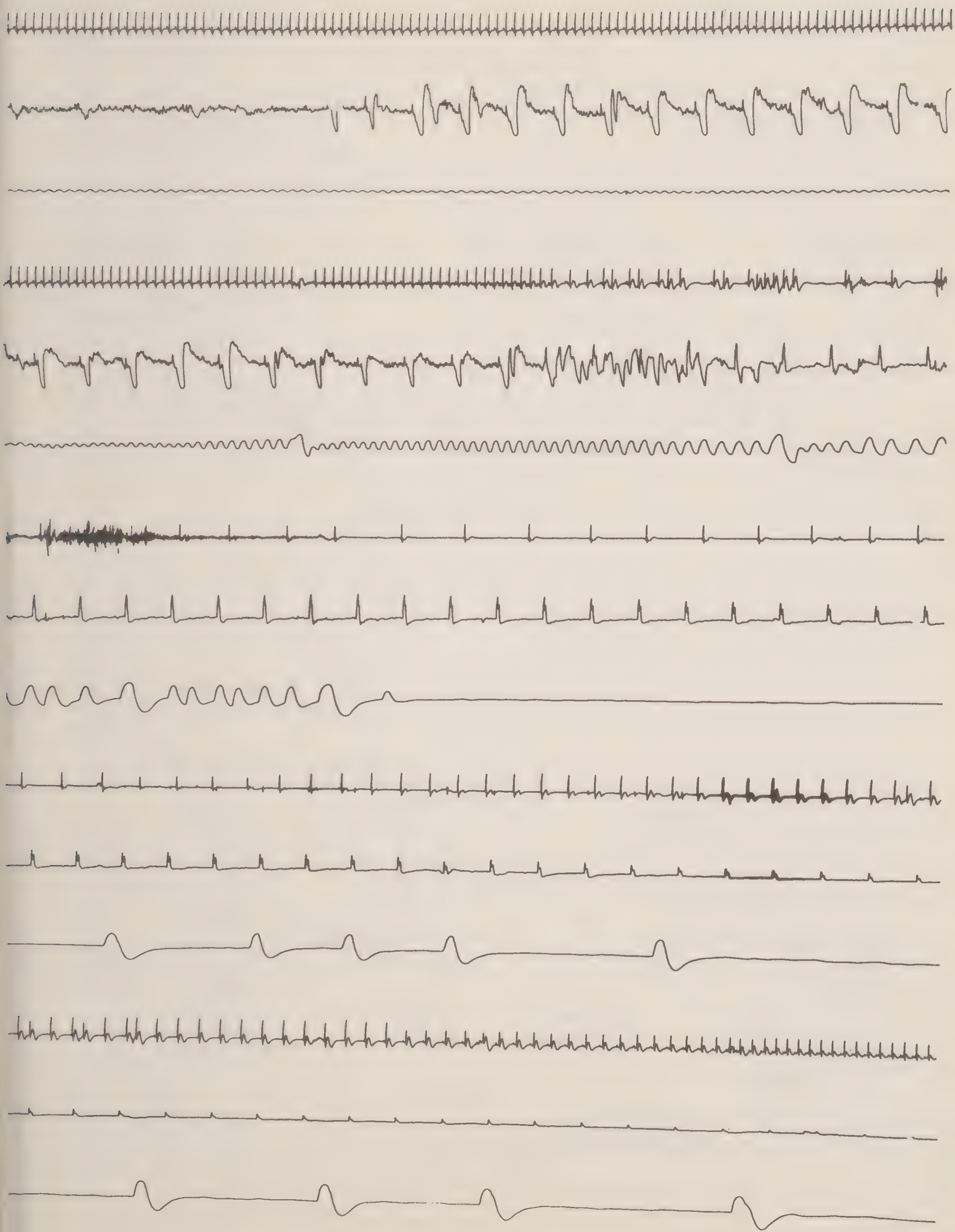


Figure 2

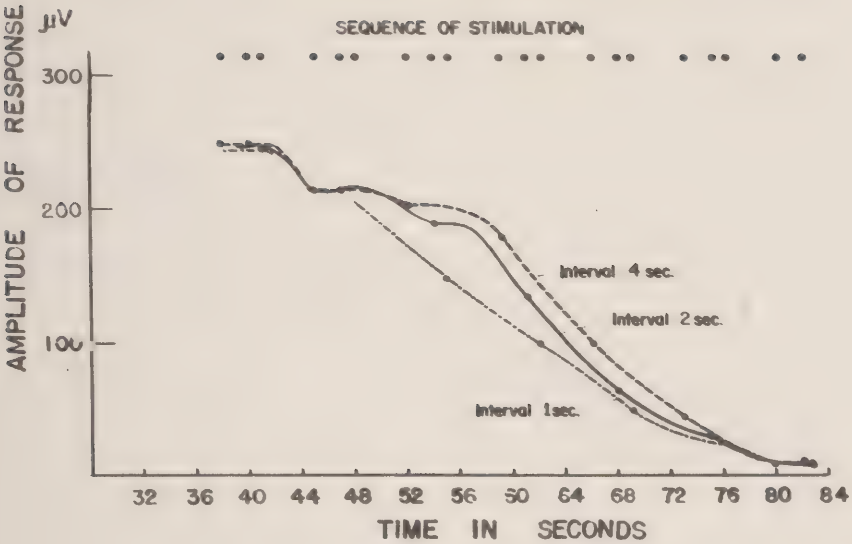


Figure 3

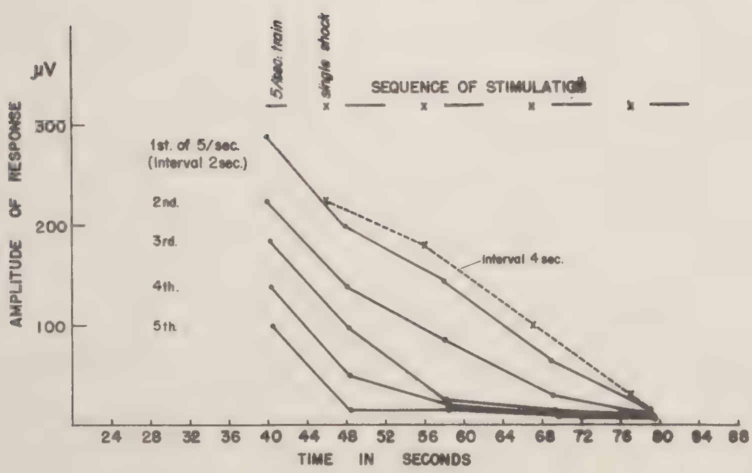


Figure 4

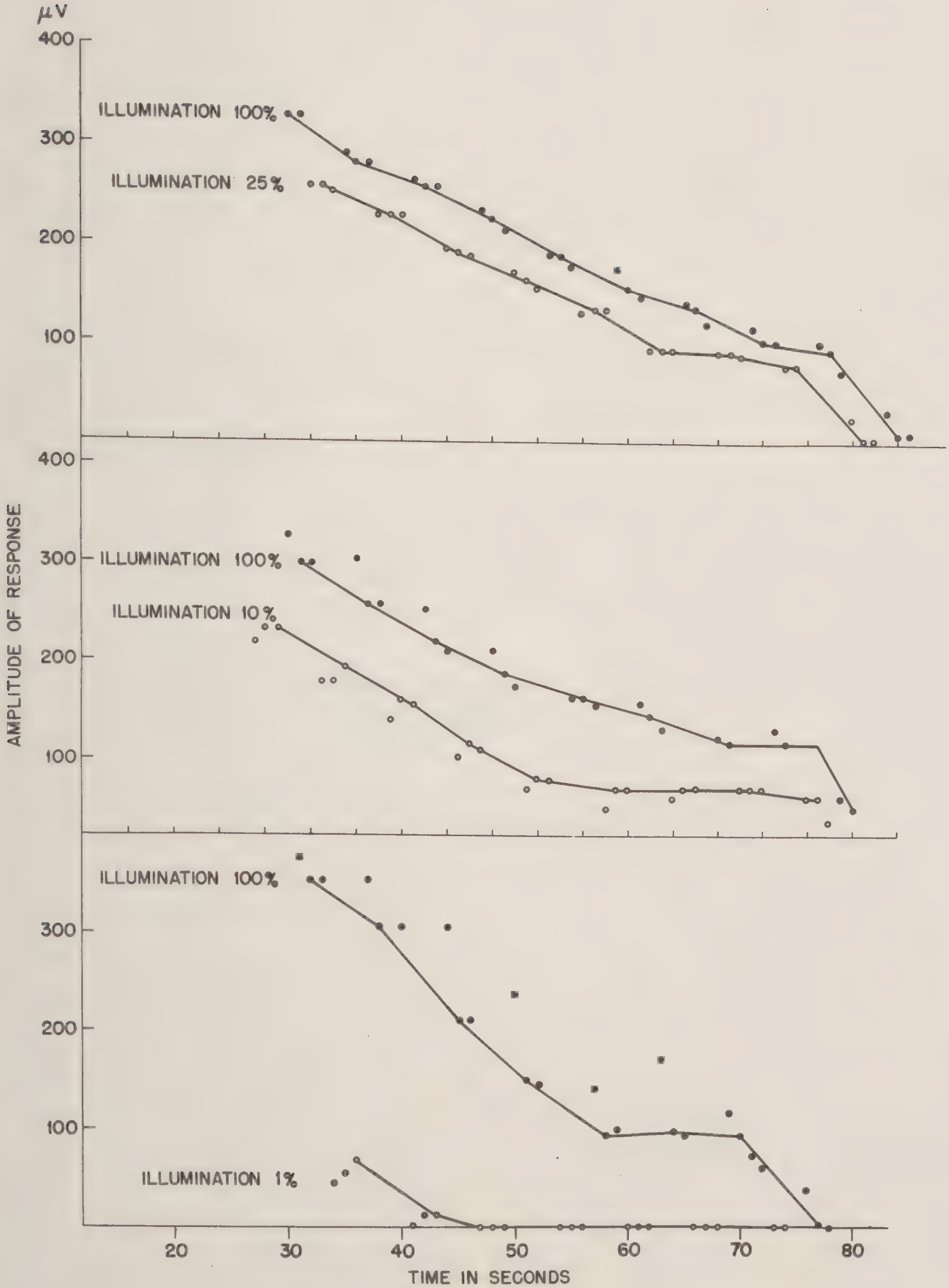

μV
400
300
200
100
ILLUMINATION 100%
ILLUMINATION 25%
400
300
200
100
ILLUMINATION 100%
ILLUMINATION 10%
AMPLITUDE OF RESPONSE
300
200
100
ILLUMINATION 100%
ILLUMINATION 1%
20
30
40
50
60
70
80
TIME IN SECONDS

Figure 5

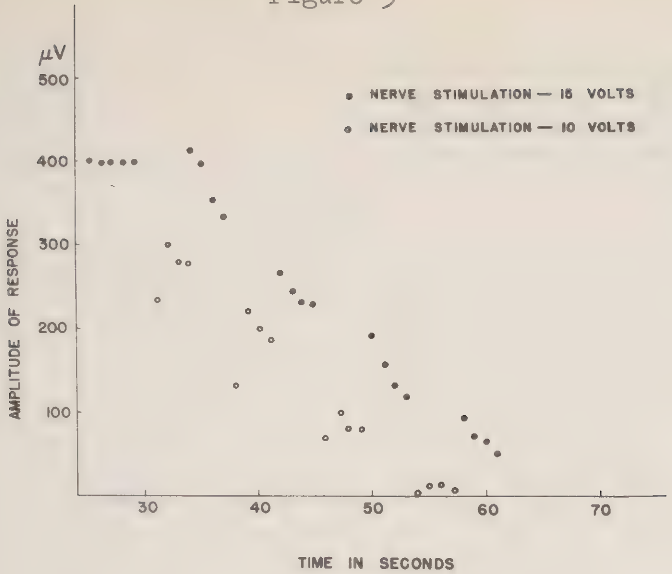


Figure 6

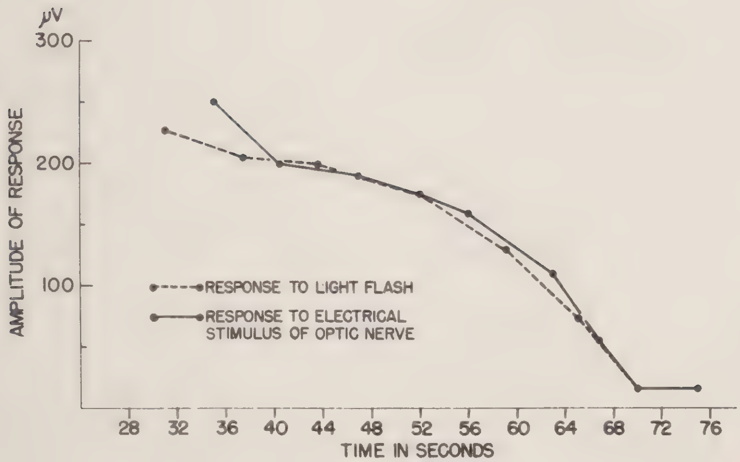
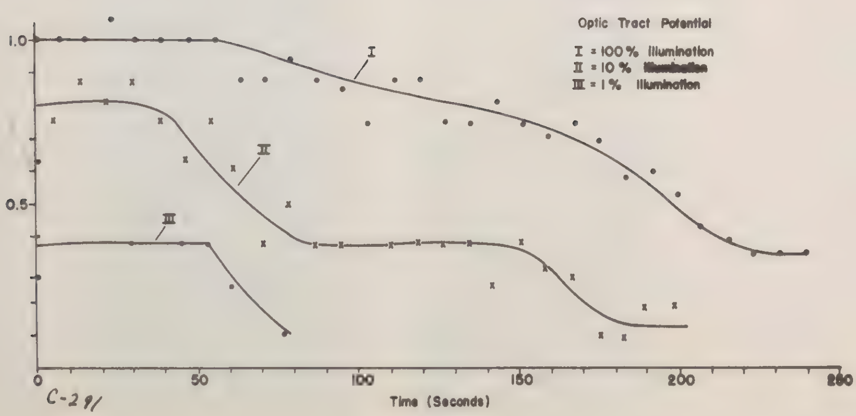


Figure 7



C-291

Figure 8

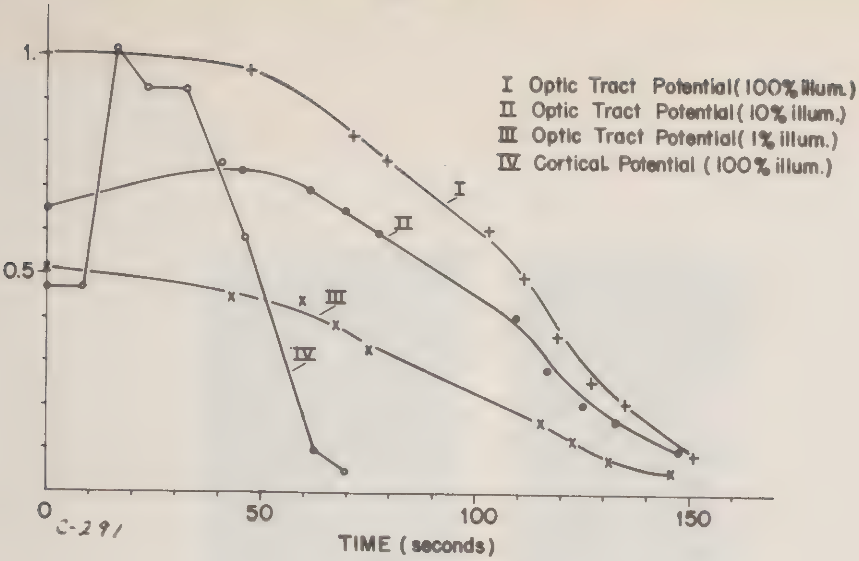


Figure 9

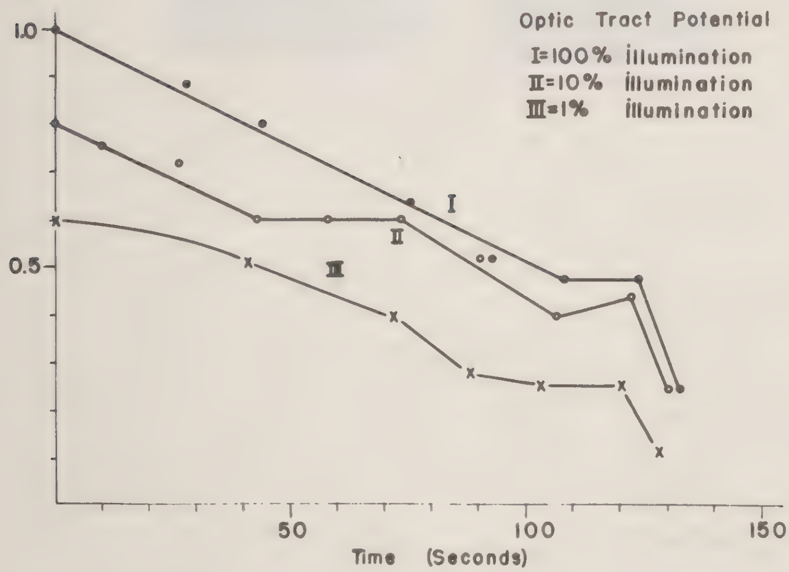


Figure 10

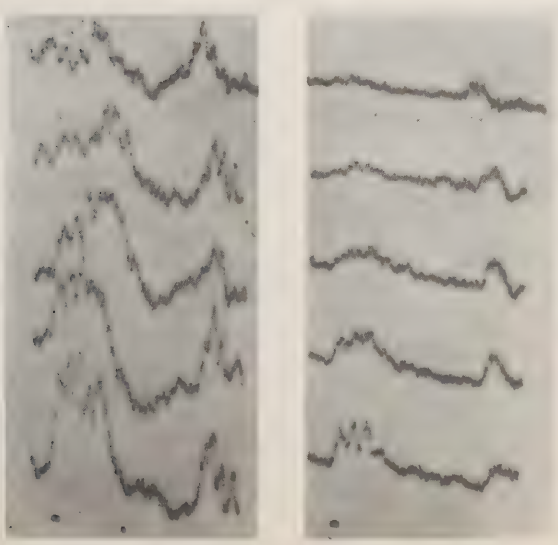


Figure 11

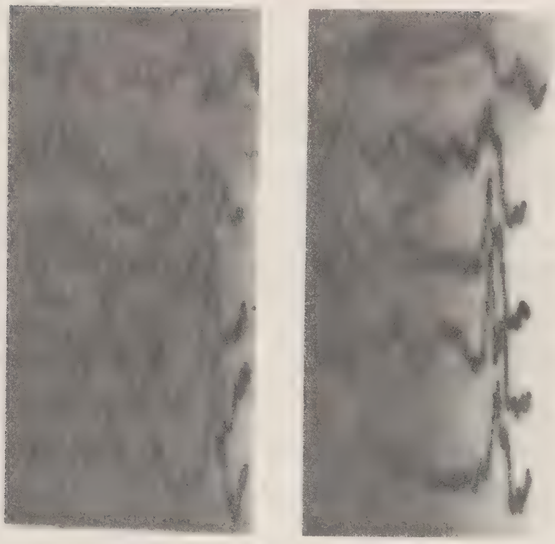
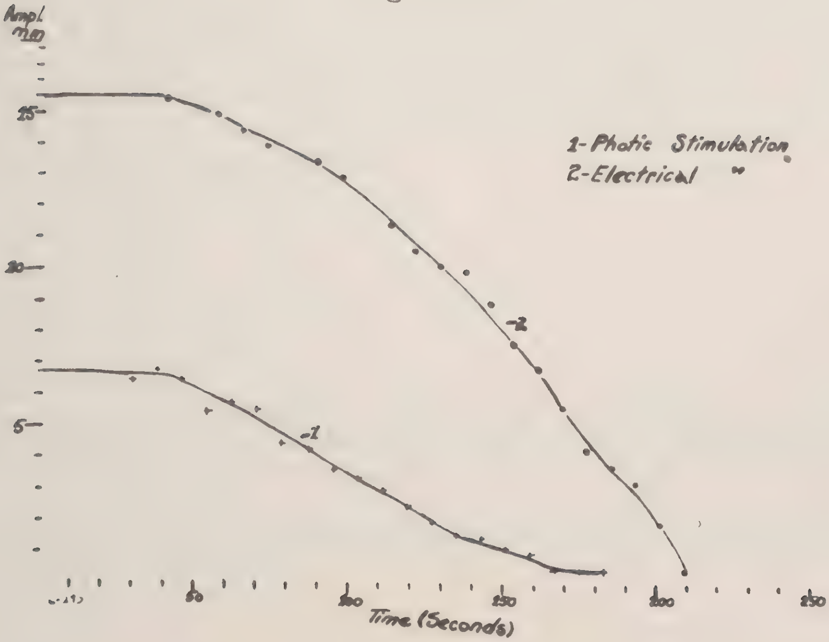


Figure 12



An Interim Report on an Experimental Study on Fatigue of Accommodation: II. Evaluation of Measures of Near Point of Accommodation and of Muscle Balance in Relation to Work on the Ophthalmic Ergograph*‡

Conrad Berens, M. D.
and
Saul B. Sells, Ph. D.

Introduction

Design.- Our previous paper (1) outlined the design of this research. Fifty-seven civilian subjects, twenty-one male and thirty-six female, ranging in age from nine to fifty-four years, were tested in twelve experiments. These subjects were selected by a hospital clinic ophthalmologist for referral on the basis of symptoms of asthenopia and complaints of ocular fatigue. Patients with pathologic eye conditions or squint were not referred. High motivation to cooperate with the research was obtained by the device of having the referring ophthalmologist inform the patients that they were to receive exercises for the eye muscles. Because of this explanation, despite boredom and the inconvenience of returning a number of times, the subjects appeared to comply with instructions and to manifest much interest in their performances.

The details of the experimental design are as follows. Each subject was used as a control on himself in twelve experiments, in which three conditions were varied. These were a) ergograph eye treatment (EET), consisting of a separate series of experiments in which the right eye (RE) was tested on the ergograph with LE occluded, LE with RE occluded and binocular series (OU); b) illumination, in which half of the ergograph runs were at five foot-candles and the other half at fifty foot-candles; and c) test object, in which half of the ergograph runs employed a fine double line cross as test object, and the other half photographically reduced letters on a Berens accommodation card. Thus the twelve experiments, in combination, consisted of 1) RE + 5 fc., 2) LE + 5 fc, 3) OU + 5 fc, 4) RE L 5 fc, 5) LE L fc, 6) OU L 5 fc, 7) RE + 50 fc., 8) LE + 50 fc., 9) OU + 50 fc., 10) RE L 50 fc., 11) LE L 50 fc., 12) OU L 50 fc. Each ergograph work period was thirty minutes, except in cases where the subject was unable to complete the task because of excessive fatigue, pain, or discomfort. Normal correction was worn throughout.

*Acknowledgment is made of statistical advice and computing assistance of Mr. Allyn Kimball, Department of Biometrics and Dr. John Willmann, Department of Psychology, U.S.A.F. School of Aviation Medicine, Randolph A.F.B., Texas.

‡This study was aided by grants from the National Research Council and the Ophthalmological Foundation, Inc.

Immediately before each ergograph run and immediately following each run a series of measurements was taken for each subject. These consisted of muscle balande at 25 cm. and 6 meters, using Maddox rods, and near point of accommodation for R.E., L.E. and O.U. These measures are designated as MB-251 (muscle balance, 25 cm., initial), MB-61, NPA-RE-I, NPA-LE-I, NPA-OU-I, and the comparable final measures with the designated as decrements, and follow the same notation, using the designation D. To distinguish references to RE, LE, OU as experimental conditions under EET from those used to designate initial and final measures, the latter will be referred to as eye measured, EM. A uniform procedure was followed for all initial and final measures, which were taken at ten foot-candles of illumination.

Resume of Previous Results.- The previous report of this research (1) presented the gross results concerning changes in near point of accommodation following ergograph exercise. All of the thirty-six critical ratios of differences between initial and final near points of accommodation (NPA_D) were significant beyond the .01 level. This was interpreted to indicate that a statistically significant loss of accommodative powere occurred in the population tested as a result of the ergograph exercise. In addition, it was found that the decrement in eye measured (EM) was greater in each case for the eye worked (EET) than for the eye occluded in the ergograph period, although both were statistically significant. These results confirm the expectation that both eyes will manifest decrement ("fatigue"), even when only one works while the other is occluded. The differential effect, however, may be attributed to the fact that for any given EET the result for the corresponding EM is direct while for the other it is a product of neuromuscular interaction.

Presentation of Additional Results

Plan of Present Paper.- Further analysis of the data of this research was interrupted by the war. The present paper reports a differential evaluation of personal and experimental factors related to the near point and muscle balance decrements. The personal factors include age and refractive error under cycloplegic. The principal experimental variables are illumination level and type of test object.

Relation of NPA_I and NPA_D to Age.- Tables 2 through 13, in the previous paper (1) presented the Mean NPA_I, NPA_F and NPA_D for RE, LE and OU for each of the twelve experiments, for the entire group of 57 subjects. Tables in this report begin with number 14. Tables 14 and 15 present a further breakdown of Tables 2 through 13, showing the same comparisons for three age intervals - over 30 years, 15 to 30 and 9 to 14. Table 14 reports Mean NPA_F, NPA_I and NPA_D for eact category, together with the corresponding critical ratio of the difference. Table 15 reports the standard deviations corresponding to the respective Mean NPA_I and NPA_F.

Although the numbers of cases for age groups are small, the same relationships between initial and final near points previously found for the entire group appear among age sub-groups. Of 108 critical ratios reported in Table 14, 62 are significant to the .01 level, 28 to the .05 level and 18 are above the .05 level, of which eleven are in the above 30 group, which consists of only six subjects. It is apparent from Tables 14 and 15 that the general

significance of the near point of accommodation decrement previously reported for the entire group holds for the age sub-groups as well. This internal consistency within age sub-groups also refutes the possible criticism that the relationships found might be attributed to heterogeneity of data due to the wide age range of the entire group.

Table 14 indicates a trend for both initial near points of accommodation and near point decrements to increase with age. The relation of accommodation to age, which is well-known, is further demonstrated by correlating mean initial near points with age. Mean initial near points for RE, LE, and OU were computed by averaging the twelve NPA_I measures for each eye. These correlations are .609, .630, and .608 for RE, LE and OU respectively.

In Table 15, it appears that the standard deviations increase with age. This would suggest greater variability among older people in accommodative power. We have attempted to check whether such variability also exists within the individual by computing a range of NPA_I score for each subject. This was obtained by finding the difference between the highest and lowest NPA_I among the 36 NPA_I measures for each subject. The mean range for the distribution is 5.32 cm. and the standard deviation 1.92. The allowing for a difference of .8 cm. between the total group mean NPA_I for RE (or LE) and OU, it is nevertheless apparent that individual variability is a significant fact. The correlation of near point range with age is .293. This correlation coefficient is significant. It indicates a low, but positive tendency for individual variability in accommodative power to increase with age.

A table evaluating differences between age group decrement means in Table 14 is not given here, although one can be computed from the data in Tables 14 and 15. Satisfactory evidence on the significance of the relation of near point decrement to age is obtained from two other sources. First, the variance attributable to age among near point decrement measures was evaluated by computing the value of the ratio F by dividing Mean Square among Means of Age Groups by estimate of error in Table 25. This ratio is significant beyond the .01 level. Second, the correlation of NPA_D with age is .251 for RE, .254 for LE, .345 for OU, and .285 for total decrement (the sum of total decrement for RE, LE and OU). These correlations are significant. From these several indices it may be concluded that there is a low, but positive tendency for loss of accommodative power following ergograph exercise to increase with age. This loss, or fatigue effect, is temporary. Data are not available in this research concerning the course of recovery. This is an interesting point, which should be investigated.

Relation of Near Point Decrement to Initial Near Point.- Is accommodative decrement a function of accommodative power? In view of the relation of accomodative decrement to age, stated above, it would be expected that at least the same degree of relationship would be found between average initial near points and corresponding decrements. The correlation coefficients are given in Table 16.

Each of these coefficients is significant. While they are somewhat higher than the age-decrement correlations, they are consistent with that relationship, and indicate a tendency for those with relatively poorer accommodation to experience greater decrements following ergograph exercise.

Other Indices Associated with Near Point Decrement.- The relation of the near point decrement to several other available indices was measured. These include a) refractive error under cycloplegic, b) muscle balance, both near and distance, c) the kymograph tracings of ergograph records, and d) time per ergograph run.

TABLE 14

COMPARISON OF MEAN INITIAL AND FINAL NEAR POINTS OF ACCOMMODATION
BY AGE SUB-GROUPS AND TOTAL GROUP
FOR 12 EXPERIMENTS, AS LABELED

For each experiment, the eye performing on the ergograph, the illumination of the ergograph and the test object are stated. Initial near points were taken for RE, LE, and OU prior to each ergograph experiment, regardless of eye to be used, and final measures taken immediately after. Initial and final measures were all taken uniformly at 10 foot candles of illumination. All measures are in centimeters.

EXPERIMENT 1
Right Eye cross 5 f.c.

		RE (Ergograph, LE occluded)				LE				OU			
Age Group	N	M_1	M_f	M_d	d/d	M_1	M_f	M_d	d/d	M_1	M_f	M_d	d/d
Over 30	6	15.17	19.17	4.00	2.23	16.00	18.00	2.00	2.15	13.83	16.33	2.50	3.52
15-30	20	10.40	13.50	3.10	4.03	10.55	12.00	1.45	2.73	8.95	10.50	1.55	2.77
9-14	31	9.65	12.16	2.51	4.65	10.16	11.74	1.58	2.68	8.94	10.35	1.41	2.66
Total	57	10.49	13.37	2.88	6.13	10.91	12.49	1.58	4.27	9.46	11.04	1.58	4.39

EXPERIMENT 2
Left Eye cross 5 f.c.

		RE				LE (Ergograph, RE occluded)				OU			
Over 30	6	14.00	17.83	3.83	1.61	15.17	18.17	3.00	1.28	13.17	16.00	2.83	2.13
15-30	20	10.55	11.95	1.40	2.22	10.80	12.70	1.90	2.44	9.75	10.65	.90	1.10
9-14	31	10.13	11.45	1.32	2.59	9.97	13.32	3.35	5.32	9.52	10.71	1.19	2.84
Total	57	10.68	12.47	1.79	2.80	10.81	13.61	2.80	5.72	9.98	11.25	1.27	2.89

EXPERIMENT 3
Both Eyes cross 5 f.c.

		RE				LE				Ou (Ergograph)			
Over 30	6	14.83	16.00	1.17	.84	14.50	16.50	2.00	1.68	15.67	15.17	-.50	.19
15-30	20	10.33	12.50	2.20	3.06	10.25	12.25	2.00	2.99	9.95	12.45	2.50	2.14
9-14	31	10.26	12.00	1.74	3.35	10.06	12.27	2.21	3.95	9.32	12.45	3.13	5.40
Total	57	10.75	12.60	1.85	3.25	10.60	12.70	2.10	2.84	10.21	12.25	2.04	3.65

EXPERIMENT 4
Right Eye letters 5 f.c.

		RE (Ergograph, LE occluded)				LE				OU			
Age Group	N	M_1	M_f	M_d	d/d	M_1	M_f	M_d	d/d	M_1	M_f	M_d	d/d
Over 30	6	15.83	19.67	2.84	1.82	15.33	18.67	3.34	2.21	13.83	20.00	6.17	2.57
15-30	20	10.60	12.80	2.20	2.86	10.55	12.15	1.60	2.76	9.90	11.50	1.60	3.27
9-14	31	10.35	13.03	2.68	3.95	10.10	12.00	1.90	3.28	9.35	10.71	1.36	3.68
Total	57	11.02	13.56	2.54	5.19	10.89	12.75	1.86	4.53	10.02	11.97	1.95	5.00

EXPERIMENT 5
Left Eye letters 5 f.c.

		RE				LE (Ergograph, RE occluded)				OU			
Over 30	6	16.50	21.17	4.67	4.06	16.33	22.83	6.50	8.90	15.83	20.33	4.50	3.21
15-30	20	10.60	12.50	1.90	2.79	10.55	13.15	2.65	3.53	10.15	11.40	1.25	2.27
9-14	31	10.61	11.77	1.16	2.52	10.74	12.45	1.71	3.89	9.71	10.58	.87	2.35
Total	57	11.23	13.02	1.79	4.84	11.25	13.79	2.54	6.05	10.51	11.89	1.38	3.94

EXPERIMENT 6
Both Eyes letters 5 f.c.

		RE				LE				OU (Ergograph)			
Over 30	6	16.33	20.67	4.34	4.37	15.17	20.33	5.16	5.61	15.50	20.83	5.33	2.35
15-30	20	10.15	11.35	1.20	1.85	10.55	11.45	.90	1.53	9.70	11.20	1.50	2.63
9-14	31	10.23	11.10	.87	1.58	10.26	11.52	1.26	2.52	9.97	11.58	1.70	2.93
Total	57	10.84	12.18	1.34	3.83	10.88	12.25	1.37	3.34	10.46	12.16	1.70	4.47

TABLE 14 (Continued

EXPERIMENT 7
Right Eye cross 50 f.c.

Age Group	N	RE (Ergograph, LE occluded) M_l	M_f	M_d	d/d	LE M_l	M_f	M_d	d/d	OU M_l	M_f	M_d	d/d
Over 30	6	16.33	18.67	2.34	1.54	16.50	19.00	2.50	1.33	15.00	17.00	2.00	.98
15-30	20	10.65	13.05	2.40	2.73	10.75	12.30	1.55	1.87	9.40	11.60	2.20	2.75
9-14	31	10.13	11.45	1.32	2.94	10.10	11.10	1.00	2.13	9.52	11.10	1.58	2.98
Total	57	10.96	12.77	1.81	4.90	11.00	12.35	1.35	3.30	10.05	11.89	1.84	4.00

EXPERIMENT 8
Left Eye cross 50 f.c.

		RE				LE (Ergograph, RE occluded)				OU			
Over 30	6	15.67	19.33	3.66	2.42	16.00	19.00	3.00	2.26	14.67	17.50	2.83	2.11
15-30	20	10.65	12.30	1.65	2.62	10.75	12.80	2.05	3.06	9.85	11.40	1.55	2.42
9-14	31	9.71	11.52	1.81	2.92	10.00	12.23	2.23	3.33	9.42	10.87	1.45	2.50
Total	57	10.67	12.44	1.77	3.85	10.89	13.14	2.25	5.00	10.12	11.75	1.63	3.70

EXPERIMENT 9
Both Eyes cross 50 f.c.

		RE				LE				OU (Ergograph)			
Over 30	6	15.83	19.67	3.84	3.00	16.33	19.17	2.84	1.93	15.00	20.50	4.50	4.25
15-30	20	10.20	12.15	1.95	2.94	10.15	11.85	1.70	2.46	9.15	11.25	2.10	2.80
9-14	31	9.97	11.61	1.64	2.83	9.97	11.74	1.77	3.29	9.58	11.94	2.36	4.07
Total	57	10.67	12.65	1.98	4.95	10.67	12.56	1.89	4.72	10.00	12.44	2.44	5.95

EXPERIMENT 10
Right Eye letters 50 f.c.

Age Group	N	RE (Ergograph, LE occluded) M_l	M_f	M_d	d/d	LE M_l	M_f	M_d	d/d	OU M_l	M_f	M_d	d/d
Over 30	6	16.33	20.67	4.34	217.00	15.67	20.67	5.00	9.44	13.33	19.50	6.17	5.36
15-30	20	10.05	12.25	2.20	2.59	9.95	11.40	1.45	2.10	9.25	10.60	1.35	2.37
9-14	31	9.74	12.16	2.42	4.10	9.68	11.19	1.51	3.68	9.42	10.74	1.32	2.70
Total	57	10.54	13.09	2.55	6.22	10.40	12.30	1.90	4.87	9.80	11.61	1.81	4.52

EXPERIMENT 11
Left Eye leters 50 f.c.

		RE				LE (Ergograph, RE occluded)				OU			
Over 30	6	15.67	20.17	4.50	4.41	15.67	21.50	5.83	7.02	15.00	19.67	4.67	2.93
15-30	20	10.05	11.45	1.40	2.12	9.90	12.05	2.15	2.83	9.30	10.75	1.45	2.54
9-14	31	9.90	11.29	1.39	2.84	9.94	11.90	1.96	3.44	9.32	10.87	1.55	3.87
Total	57	10.56	12.28	1.72	57.40	10.53	12.96	2.43	5.40	9.91	11.75	1.84	5.10

EXPERIMENT 12
Both Eyes letters 50 f.c.

		RE				LE				OU (Ergograph)			
Over 30	6	16.17	20.33	4.16	2.20	15.67	20.50	4.83	1.94	15.00	21.50	6.50	7.15
15-30	20	10.35	11.20	.85	1.47	10.05	10.90	.85	1.47	9.20	11.00	1.80	2.47
9-14	31	9.58	11.29	1.71	3.29	9.94	11.71	1.77	3.22	9.23	11.55	2.32	4.07
Total	57	10.54	12.21	1.67	3.71	10.58	12.35	1.77	3.94	9.82	12.42	2.60	4.26

[redacted]

TABLE 15. Table of Standard Deviations - Near Point of Accommodation.

Age Group	N	RE I	RE F	LE I	LE F	OU I	OU F	RE I	RE F	LE I	LE F	OU I	OU F
		EXPERIMENT 1						EXPERIMENT 2					
Over 30	6	3.01	5.22	3.65	3.74	3.15	3.32	2.16	5.53	2.72	5.39	2.39	4.40
15 - 30	20	2.03	4.31	2.40	3.03	1.63	2.54	2.52	3.60	2.44	4.33	2.76	3.33
9 - 14	31	1.37	3.30	1.89	3.82	1.45	2.73	2.10	4.49	1.70	4.36	2.14	3.50
		EXPERIMENT 3						EXPERIMENT 4					
Over 30	6	2.86	5.20	2.93	5.03	2.73	6.09	5.28	6.55	5.20	6.59	5.47	6.51
15 - 30	20	2.17	4.08	2.09	4.19	2.56	4.97	2.11	3.42	2.33	3.25	2.07	2.42
9 - 14	31	1.78	3.66	2.05	4.14	1.92	4.19	1.71	4.53	2.15	4.01	2.05	3.37
		EXPERIMENT 5						EXPERIMENT 6					
Over 30	6	4.65	4.43	4.83	3.15	5.28	5.03	4.55	4.33	4.30	4.97	5.25	4.89
15 - 30	20	2.04	3.32	2.13	4.00	2.01	3.04	1.65	2.96	1.83	2.98	1.38	2.83
9 - 14	31	2.39	3.19	2.62	3.64	2.11	3.13	1.87	3.34	2.45	3.21	2.20	3.65
		EXPERIMENT 7						EXPERIMENT 8					
Over 30	6	4.65	5.70	4.54	4.58	4.10	5.07	5.58	6.22	4.83	5.57	3.89	4.86
15 - 30	20	1.98	4.30	2.10	3.84	1.28	3.64	2.11	3.74	2.39	4.39	2.01	3.41
9 - 14	31	2.11	3.75	1.96	3.59	2.06	3.80	1.89	3.85	2.12	4.54	1.82	3.54
		EXPERIMENT 9						EXPERIMENT 10					
Over 30	6	4.82	4.57	4.40	4.36	4.16	4.62	3.00	3.28	2.91	3.12	1.41	2.50
15 - 30	20	1.81	4.00	1.85	4.20	1.80	4.25	1.83	4.32	2.13	3.82	1.87	3.40
9 - 14	31	2.59	4.33	2.42	3.88	2.58	4.55	2.01	4.26	1.96	3.71	1.89	3.34
		EXPERIMENT 11						EXPERIMENT 12					
Over 30	6	3.33	3.74	2.78	4.01	2.58	5.08	3.96	3.37	3.58	3.99	3.32	4.62
15 - 30	20	2.36	3.26	2.30	4.10	1.82	2.77	2.22	3.43	1.36	3.77	1.36	3.79
9 - 14	31	2.08	3.14	2.12	4.34	1.94	3.03	2.45	4.13	2.52	4.63	2.31	4.70

[redacted]

Table 16.- Correlations Between Average Initial Near Points and Total Near Point Decrements

NPA_I	NPA_D RE	LE	OU
RE	.309	.353	.386
LE	.331	.370	.402
OU	.336	.374	.409

Table 17.- Means and Standard Deviations of Muscle Balance Distributions

	MB-25-I	MB-25-D	MB-61-I	MB-6-D
Mean	105.32	100.74	96.32	99.47
S.D.	43.95	9.13	28.20	8.42

Table 18.- Correlations Between Muscle Balance and Near Point Measures

	NPA_I				NPA_D			
	RE	LE	OU	Range	RE	LE	OU	Total
MB-25-I	.031	.026	.054	.208	-.016	-.101	-.003	-.042
MB-25-D	.107	.108	.125	.076	.144	.092	.192	.141
MB-6-I	-.007	-.027	-.006	.112	.075	.004	.107	.063
MB-6-D	.043	.041	.012	-.043	-.077	-.100	.006	-.067

Table 19.- Mean Near Point Decrement By Type of Curve and Age Group

		Mean Decrement (NPA_D - EM by EET)		
Type of Curve		Flat	Decrement	INcrement
Age Group	N			
Over 30	6	2.63	5.41	1.83
15 - 30	20	.16	3.41	-.03
9 - 14	31	1.29	2.09	.21
Total	57	1.08	3.74	.34

a) To investigate a possible relation of near point decrement to refractive error under cycloplegic, the total decrement score for each subject (representing the algebraic score of all 36 individual decrement measures) was arrayed in descending order from greatest to least decrement. The refractive findings were then tabulated for each subject. No relation was found. Inasmuch as all subjects were tested wearing normal correction it is possible only to suggest that accomodative fatigue is not correlated with refractive error when adequate correction is worn.

b) Correlations were computed between muscle balance measures and near point decrement. To obtain a quantitative measure of lateral phorias the following procedure was used: Esophoria was considered as a negative deviation, orthophoria as zero deviation and exophoria as positive. Scores were computed in prism diopters taking the algebraic sign into consideration. For ease of handling, 100 was added to each score. Thus a score of 100 means orthophoria, below 100 esophoria and above 100 exophoria. A muscle balance decrement was computed in the same manner as for near points by subtracting initial muscle balance score from final. Hence we have four average muscle balance measures, each of which represents the aggregate of twelve experiments: MB-25-I, MB-25-D, MB-6-I, MB-6-D. The means and standard deviations of these measures are given in Table 17.

Thus (dividing 5.32 by 12) the mean initial muscle balance at 25 cm. is equivalent to .44 prism diopters of exophoria and at 6 meters it is .31 prism diopters of esophoria. The difference between the two initial muscle balance means is greater than that between medians, which are 99.40 (.05 Eso.) and 97.47 (.21 Eso.) respectively. The higher mean of the MB-25-I distribution is caused by seven scores above 160, which are above the range of the other distribution. The mean differences indicate less than .05 diopter of mean net change, although the range of variations is fairly large. The correlation between MB-25-I and MB-6-I is .812, which indicates a high relationship between the two among these subjects.

The correlations between muscle balance measures and near point measures are presented in Table 18.

None of these correlations is significantly different from zero and it is concluded that no relationsexists between muscle balance and accommodation.

c) The initial and final near point and muscle balance measures were taken in a standard manner under 10 foot-candles of illumination both before and after the ergograph runs. The kymograph tracings obtained from the ergograph runs constitute an additional source of data. In order to handle these tracings more easily each one was measured and the length of each stroke recorded. They were then individually plotted by averaging five strokes at each half minute interval. The tracings were classified crudely into four groups: a) flat, b) decrement, c) increment, d) variable. Two analyses of these tracings were made in relation to the near point decrements. First, the number of decrement tracings (out of a total possible of twelve) was computed for each subject. The mean number of decrement tracings for the total group is 4.3 and the standard deviation 3.26. By age groups, the comparable means are: 9 to 14 years, 4; 15 to 30, 4.4; and over 30, 5.5. The correlation between number of decrement tracings and total near point decrement is .715. The correlation of this variable with other related variables is as follows:

with muscle balance variables: not significant
age: .133
initial near points: from .133 to .211
NPA_D: RE .734, LE .720, OU .665.
total time: -.519

In general the number of decrement curves is a function highly related to near point decrement and it varies similarly with other variables.

A second analysis of the kymograph tracings was made by computing the near point decrement associated with each curve. The decrement measure used was that for the eye corresponding to the EET for the particular experiment. Table 19 shows the mean decrement for flat, decrement and increment curves, by age groups. Curves classified as variables are not included because they are few in number.

It will be noted that the mean near point decrement associated with decrement curves, for the total group is 3.74, in contrast to 1.08 for flat curves and .34 for increment curves. Clearly, the decrement curve reflects the same information as the near point decrement (NPA_D). The increase in amount of decrement with age is also demonstrated. Further analysis of the kymograph tracings will be presented in a later paper.

d) Although the time for each ergograph run was thirty minutes, many were terminated before that time at the subject's request because of complaints of constant blurring of the test object over the entire range of travel, extreme and painful eyestrain, headache, or similar reason. The reasons given were analyzed, but were found too unreliable to use for any analytical purpose. However, the time for each run was recorded. We computed the total time for twelve runs per subject, for which the maximum would be 360 minutes. The mean total time for the entire group is 220.12 minutes with a standard deviation of 60.47. None of the group was able to run for the entire time, although one attained a total time score of 340 minutes and six were over 300. The correlation of total time with related indices is as follows:

with age: -.345
number of decrement tracings: -.519
NPA_D: RE -.553, LE -.554, OU - .564, Total -.572
NPA_I: RE -.388, LE -.338, OU -.357, Range -.318
muscle balance: not significant

From these correlation coefficients it appears a) that the amount of time a subject can persist in constant visual pursuit of the test object decreases with age: b) that the greater the number of decrement tracings the shorter the time per session; c) that the greater the near point decrement, the shorter the time per session; d) that the greater the initial near point of accommodation (i.e., the less the initial accommodative power) the shorter the time per session. Time per session, then, may be regarded as another index of accommodation fatigue. Its significance as such an index, however, depends upon having high motivation and compliance by the subject, as in these experiments.

Relation of Near Point Decrement of Eye Measured to EET.- Our previous paper, as summarized above, reported significant decrements for the eye occluded during the ergograph session, although these were found to be of lesser magnitude than the decrements for the eye which worked. Table 20 restates this finding in a

more direct way. It presents the mean decrement for each eye measured, computed according to EET. In other words, for EET condition REwe have four experiments: RE 5, L5, 50, L50. For each experiment we have three NPA_D measures or EM-RE, EM-LE and EM-OU. Hence the figures in the first column, under RE constitute the average of the four EM-RE, EM-LE and EM-OU decrements respectively from the four EET-RE experiments. The other columns are similarly derived.

A test of significance was applied to the differences between the means in the preceding table. This was done by computing the ratio F for the Mean Square of Interaction of EET and EM divided by experimental error in Table 25. This F ratio is 11.82 which is significant beyond the .01 level. Thus the interaction previously noted is found to be a statistically significant relationship.

Reliability of Near Point Data.- Tables 30 and 31 give the intercorrelations of individual initial near points and near point decrements. It will be noted that these are of high order. The intercorrelations of the average measures, obtained by combination are given in Table 21.

Analysis of Muscle Balance Data.- We have already described the method employed for quantitative analysis of lateral phorias. Vertical phorias have not yet been analyzed. The distribution of the entire group with respect to average initial muscle balance scores is given in Table 22.

Both distributions are fairly symmetrical and contain approximately equal numbers of esophoric and exophoric cases. However, the range of exophoria is curtailed when measurements are at 6 meters distance as contrasted with 25 centimeters. It appears that this is more probably a function of the method of testing than a significant difference in true muscle balance. The lateral adjustment is probably more marked at the near point.

It has already been shown that muscle balance is unrelated to accommodation and to age. However, it is necessary to inquire into the effect or ergographic exercise on muscle balance. The accommodation pursuit is simultaneously a convergence exercise and it is expected that an observable effect should be found.

Correlations were computed between initial and decrement average muscle balance scores for near and distance measures. These are .354 for near and .618 for distance. The correlation between the two decrement scores is .511. It appears then that the two measures are related and that the effect of ergograph (convergence-accommodation) exercise on lateral muscle balance is to increase the phoria in the direction of the original displacement. While the correlation coefficient for near is relatively low, it is significant. The coefficient for six meters represents a fairly high relationship.

To inquire further into the nature of this relationship we have made an analysis of individual cases. Tables 23 and 24 show the number of cases and net positive and negative change for each set of measures when the entire group is classified according to initial muscle balance. The relationships disclosed in these tables are consistent with the correlation coefficients. In both tables there are reversals, although the trend toward increase in the direction of initial phoria is more pronounced at 6 meters. There is a tendency for this relationship to occur more clearly with extreme cases.

Table 20.- Mean Near Point Decrement for EET-EM Interaction

EET-Ergograph Eye Treatment
EM-Eye Measured

	RE	LE	OU
RE	2.47	1.86	1.72
LE	1.69	2.51	1.81
OU	1.80	1.55	2.75

Table 21.- Intercorrelations of Average Near Point Measures

Average Initial Near Points

	RE	LE	OU
RE		.977	.968
LE			.963

Average Near Point Decrements

	RE	LE	OU	Total
RE		.981	.953	.993
LE			.939	.988
				.977

Table 22.- Distribution of Initial (Lateral) Muscle Balance at 25 Cm. and 6 Meters

	Muscle Balance Score	Equivalent Value in Prism Diopters			MB-25-I		MB-6-I	
	210-219	9.13	- 9.92	Ex	1			
	200-209	8.33	- 9.08	Ex	1			
	190-199	7.50	- 8.25	Ex	2			
Exophoria	180-189	6.67	- 7.42	Ex	2			
	170-179	5.83	- 6.58	Ex	0			
	160-169	5.00	- 5.75	Ex	1			
	150-159	4.17	- 4.92	Ex	2		1	
	140-149	3.33	- 4.08	Ex	1		3	
	130-139	2.50	- 3.25	Ex	4		4	
	120-129	1.67	- 2.42	Ex	3		4	
	110-119	.83	- 1.58	Ex	5		5	
	100-109	0	- .75	Ex	6(1) Mdn		10(2) Mdn	
	90-99	.83	- .08	Es	8	99.40	11	97.47
	80-89	1.67	- .91	Es	5		5	
	70-79	2.50	- 1.75	Es	6		6	
Esophoria	60-69	3.33	- 2.58	Es	2		3	
	50-59	4.17	- 3.41	Es	3		4	
	40-49	5.00	- 4.25	Es	2		0	
	30-39	5.83	- 5.08	Es	1		1	
	20-29	6.67	- 5.91	Es	2		1	

Notes: (1) - includes one score of 100; (2) - includes two scores of 100.

An adequate explanation of this interesting result must await further study and examination of individual cases. Unfortunately, a complete ophthalmologic examination of each subject, including convergence near point, and complete orthoptic data are not available. It is planned to investigate this problem further in new experiments.

Relation of Muscle Balance Data to Cycloplegic Refractions.- The muscle balance data were arrayed and tabulated against refractive error under cycloplegic in the same manner as the near point data, described above. No relationship was found.

Illumination and Test Object.- The twelve experiments reported herein were designed to compare the effects of two levels of illumination - 5 and 50 foot-candles, and the effects of two types of test objects - fine line cross and letters on Berens accommodation card on near point and muscle balance decrement following ergograph exercise. In these experiments each subject was a control on himself. It is believed that intra-subject variation is less than inter-subject variation which would be encountered if matched groups were employed.

The effects of illumination, test object, and individual intra-subject variation, together with those of EET, EM and the inter-actions of these variables, were tested separately for accommodation decrement and for muscle balance decrement by the method of analysis of variance. The results are reported in Tables 25, 26 and 27. Following each table the means for each of the analysis groups are reported.

These tables indicate clearly that no differential effects have been found with regard either to illumination or test object. While it was not clear how muscle balance might be related to either of these variables, there has been evidence to support the hypothesis that accommodation would be related to illumination. Ferree and Rand, (2) for example, reported an average increase in accommodative power of 1.6 centimeters related to a change from 1 to 25 foot-candles for a group of twelve subjects ranging from twenty to forty-one years in age. It was expected that, as increased illumination facilitates ease of seeing, it might offset fatigue.

In view of the negative findings with regard to decrement as a function of illumination level, we made an examination of initial near points of accommodation at three levels of illumination for which data were available. All initial near points were taken at 10 foot-candles. From the kymograph tracings it was possible to measure initial excursions at 5 and 50 foot-candles. Table 28 presents a synthesis of these data. Although there are reversals in this table, there are nevertheless some appreciable differences between near points at the three levels. It is interesting to note that differences between 5 and 10 foot-candles are greater than those between 10 and 50. Further analysis of these data has not been made. It is planned to investigate the problem of level of illumination in relation to near vision with a wider range of illuminations.

Table 23.- Relation of Muscle Balance Decrement to Initial Phoria (25 cm.)

Initial Average MB-25 Score	Equivalent Individual Phoria Score	N	Net Positive Change N	Net Positive Change Average Change	Net Positive Change N	Net Positive Change Average Change
150 +	Over 4.2 Ex	9	8	10.	1	6.
120 - 150	1.7 -4.2 Ex	8	3	13.8	5	6.4
100 - 120	0 -1.7 Ex	11	4	4.5	7	2.8
80 - 100	1.7 Es. - 0	13	7	3.7	6	4.5
50 - 80	4.2 Es. -1.7 Es	11	6	10.	5	7.
Below 50	Over 4.2 Es	5	1	1.	4	12.8

Table 24.- Relation of Muscle Balance Decrement to Initial Phoria

(6 Meters)

Initial Average MB-6 Score	Equivalent Individual Phoria Score	N	Net Positive Change		Net Negative Change	
			N	Average Change	N	Average Change
150 + over	Over 4.2 Ex	1	0	0	1	3
140 - 150	3.3 -4.2 Ex	3	3	11.7	0	0
120 - 140	1.7 -3.3 Ex	8	8	8.	0	0
100 - 120	0 -1.7 Ex	15(1)	5	4.4	6	3.5
80 - 100	1.7 Es - 0	16(2)	8	4.	7	4.4
50 - 80	4.2 -1.7 Es	12	1	9.	11	10.4
Below 50	Over 4.2 Es	2	0	0	2	7.5

Notes: (1) - includes 4 cases with no change; (2) includes 1 case with no change.

Table 25.- Analysis of Variance - Near Point of Accommodation Decrement

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
E.E.T. (among means of NPA_D by ergograph eye treatment)	2	.535	.268	.046
Illumination (among means of illumination levels)	1	.0005	.0005	.0001
Test object (among means of test objects)	1	.410	.410	.071
Residual	1	11.708	11.708	2.016
Interaction - EET x illumination	2	9.913	4.957	.854
Interaction - EET x test objects	2	39.019	19.509	3.360*
Interaction - EET x residual	2	1.960	.980	.169
EM (among means of eye measured)	2	1.635	.817	.141
Interaction - EM x EET	4	274.515	68.629	11.820**
Interaction - EM x illumination	2	13.393	6.696	1.153
Interaction - EM x test object	2	1.130	.565	.097
Interaction - EM x residual	2	.685	.343	.059
Interaction - EM x EET x (subclass of illumination plus test object plus residual	12	.456	.038	.007
Individuals (among means of individuals)	56	9752.591	174.153	29.994**
Among means of age groups	4	1072.309	268.077	46.170**
Within age groups	52	8680.282	166.929	28.750**
Sampling error (estimate of error)	1960	11380.252	5.806	
Total	2051	21522.785		

*P .05

**P .01

Table 25a.- Table of Means - Near Point of Accommodation Decrement

Age	Over 30	20 - 30	16 - 20	13 - 16	9 - 13
N	6	4	12	17	18
	3.903	2.368	1.454	2.082	1.539

EET	RE	LE	OU
	1.988	1.971	2.010

EM	RE	LE	OU
	2.015	2.004	1.950

Test Object	Cross	Letters
	2.004	1.976

Illumination	5 f-c.	50 f-c.
	1.990	1.989

Table 26.- Analysis of Variance - Muscle Balance (6 Meters) Decrement

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
EET (among means of MB-6-D by ergograph eye treatment)	2	8.430	4.215	2.102
Illumination (among means of illumination levels)	1	.211	.211	.105
Test object (among means of test objects	1	3.655	3.655	1.823
Residual	1	.842	.842	.420
Interaction - EET x illumination	2	9.219	4.610	2.299
Interaction - EET x test object	2	1.178	.589	.294
Interaction - EET x residual	2	5.535	2.768	1.380
Individuals (among means of individuals)	56	336.684	6.012	2.999**
Among means of age groups	4	16.680	4.170	2.080
Within age groups	52	320.004	6.154	3.070**
Sampling Error (estimate of error)	616	1234.930	2.005	
Total	683	1600.684		

**P .01

Table 26a.- Table of Means - Muscle Balance (6 Meters) Decrement

Age	Over 30	20 - 30	16 - 20	13 - 16	9 - 13
N	6	4	12	17	18
	.083	.083	.167	-.245	-.065

EET	RE	LE	OU
	.061	.004	-.197

Test Object	Cross	Letters
	-.117	.029

Illumination	5 f-c.	50 f-c.
	-.026	-.061

Table 27.- Analysis of Variance - Muscle Balance (25 Cm.) Decrement

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
EET (among means of MB-25-D by ergograph eye treatment)	2	10.114	5.057	1.507
Illumination (among means of illumination levels)	1	.329	.329	.098
Test object (among means of test objects)	1	.329	.329	.098
Residual	1	.037	.037	.011
Interaction - EET x illumination	2	.798	.396	.118
Interaction - EET x test object	2	5.553	2.776	.827
Interaction - EET x residual	2	8.705	4.352	1.297
Individuals (among means of individuals)	56	404.623	7.225	2.153**
Among means of age groups	4	35.190	8.798	2.621**
Within age groups	52	369.433	7.105	2.117**
Sampling error (estimate of error)	616	2067.553	3.356	
Total	683	2498.040		

**P .01

Table 27a.- Table of Means - Muscle Balance (25 Cm.) Decrement

Age	Over 30	20 - 30	16 - 20	13 - 16	9 - 13
	6	4	12	17	18
	.250	-.667	.181	.191	-.028
EET	RE	LE	OU		
	.167	.136	-.105		
Test Object	Cross	Letters			
	.088	.044			
Illumination	5 f-c.	50 f-c.			
	.044	.088			

Table 29.- Table of Intercorrelations - Experimental Variables

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Mus. Bal. 25 cm. Init.	.354	.812	.457	-.148	.255	-.078	.031	.026	.054	.208	-.016	-.101	-.003	-.042
2. Mus. Bal. 25 cm. Decr.		.548	.511	.049	-.066	-.020	.107	.108	.125	.076	.144	.092	.192	.141
3. Mus. Bal. 6 M. Init.			.618	-.060	.087	-.076	-.007	-.027	-.006	.112	.075	.004	.107	.063
4. Mus. Bal. 6 M. Decr.				-.176	.165	.071	.043	.041	.012	-.043	-.077	-.100	.006	-.067
5. No. Decr. Curves					-.519	.133	.211	.211	.196	.198	.734	.720	.665	.715
6. Total Time						-.345	-.388	-.338	-.357	-.318	-.553	-.554	-.564	-.572
7. Age (years)							.609	.630	.608	.293	.251	.254	.345	.285
8. Aver. NPA_I RE								.977	.968	.769	.309	.353	.386	.353
9. Aver. NPA_I LE									.963	.721	.331	.370	.402	.372
10. Aver. NPA_I OU										.744	.336	.374	.409	.377
11. NPA_I Range											.231	.245	.292	.258
12. Total NPA_D RE												.981	.953	.993
13. Total NPA_D LE													.939	.988
14. Total NPA_D OU														.977
15. Total NPA_D Total														

Table 30.- Intercorrelations of Initial Near Point of Accommodation

		1	2	3	4	5	6	7	8	9	10	11	12
1. RE Cross 5	RE		.669	.708	.609	.785	.666	.635	.559	.758	.700	.591	.612
	LE		.670	.744	.673	.828	.655	.685	.665	.747	.582	.649	.587
	OU		.718	.789	.639	.786	.753	.671	.732	.762	.693	.592	.665
2. RE L 5	RE			.856	.805	.675	.863	.792	.750	.775	.830	.771	.779
	LE			.848	.756	.659	.862	.810	.767	.747	.811	.800	.754
	OU			.851	.678	.682	.894	.790	.774	.735	.793	.777	.778
3. RE Cross 50	RE				.843	.662	.849	.860	.824	.752	.843	.879	.877
	LE				.802	.723	.804	.836	.786	.770	.757	.799	.780
	OU				.728	.723	.873	.792	.809	.802	.890	.826	.826
4. RE L 50	RE					.571	.830	.814	.879	.616	.779	.838	.902
	LE					.554	.760	.835	.876	.586	.716	.873	.924
	OU					.601	.695	.763	.872	.581	.697	.784	.847
5. LE Cross 5	RE						.633	.574	.535	.813	.616	.549	.573
	LE						.577	.571	.623	.787	.513	.506	.475
	OU						.680	.554	.624	.801	.612	.525	.585
6. LE L 5	RE							.775	.775	.734	.845	.821	.816
	LE							.752	.752	.739	.809	.837	.768
	OU							.803	.786	.737	.836	.829	.809
7. LE Cross 50	RE								.838	.623	.753	.901	.880
	LE								.826	.594	.742	.880	.836
	OU								.826	.597	.839	.869	.834
8. LE L 50	RE									.552	.678	.829	.901
	LE									.612	.682	.867	.903
	OU									.623	.739	.841	.924
9. OU Cross 5	RE										.770	.574	.588
	LE										.720	.563	.514
	OU										.720	.543	.624
10. OU L 5	RE											.774	.745
	LE											.770	.684
	OU											.836	.770
11. OU Cross 50	RE												.918
	LE												.920
	OU												.874
12. OU L 50	RE												
	LE												
	OU												

Table 30a.- Table of Means and Standard Deviations
Initial Near Point of Accommodation

		1	2	3	4	5	6
Means	RE	10.49	11.02	10.96	10.54	10.68	11.23
	LE	10.91	10.81	11.00	10.40	10.81	11.25
	OU	9.46	10.07	10.05	9.77	9.89	10.51
S.D.	RE	2.49	2.96	3.09	2.88	2.54	3.17
	LE	2.90	3.12	3.08	2.81	2.62	3.31
	OU	2.33	3.01	2.70	2.21	2.56	3.19

		7	8	9	10	11	12
Means	RE	10.67	10.56	10.74	10.84	10.67	10.54
	LE	10.89	10.53	10.60	10.91	10.70	10.58
	OU	10.12	9.91	9.91	10.47	10.12	9.84
S.D.	RE	3.15	2.94	2.49	2.94	3.24	3.24
	LE	3.14	2.88	2.54	2.70	3.19	3.06
	OU	2.77	2.63	2.60	3.04	3.07	2.82

Table 31.- Intercorrelations of Near Point of Accommodation Decrement

		1	2	3	4	5	6	7	8	9	10	11	12
1. RE Cross 5	RE		.192	.219	.269	.583	.340	.287	.183	.455	.199	.208	.101
	LE		.237	.186	.314	.535	.210	.250	.099	.308	.234	.210	.007
	OU		.299	.205	.233	.455	.431	.399	.215	.209	.246	.272	.014
2. RE L 5	RE			.396	.451	.381	.434	.393	.408	.444	.381	.382	.436
	LE			.274	.384	.452	.422	.343	.255	.417	.168	.325	.300
	OU			.153	.491	.419	.523	.232	.250	.196	.322	.327	.314
3. RE Cross 50	RE				.691	.342	.544	.671	.484	.453	.590	.648	.525
	LE				.611	.265	.507	.740	.573	.289	.542	.651	.595
	OU				.376	.368	.362	.615	.573	.268	.274	.591	.473
4. RE L 50	RE					.308	.537	.572	.571	.369	.610	.715	.733
	LE					.203	.614	.649	.627	.324	.663	.632	.729
	OU					.449	.553	.570	.611	.241	.542	.570	.659
5. LE Cross 5	RE						.581	.517	.496	.616	.354	.347	.303
	LE						.283	.377	.323	.688	.318	.151	.247
	OU						.414	.515	.494	.406	.401	.418	.475
6. LE L 5	RE							.704	.553	.458	.553	.615	.473
	LE							.554	.572	.422	.515	.606	.514
	OU							.581	.484	.229	.443	.551	.428
7. LE Cross 50	RE								.534	.617	.547	.759	.572
	LE								.571	.502	.514	.661	.585
	OU								.577	.296	.329	.565	.379
8. LE L 50	RE									.474	.676	.550	.699
	LE									.447	.530	.544	.777
	OU									.246	.466	.492	.518
9. OU Cross 5	RE										.433	.369	.257
	LE										.410	.326	.345
	OU										.288	.232	.011
10. OU L 5	RE											.556	.585
	LE											.398	.549
	OU											.429	.396
11. OU Cross 50	RE												.746
	LE												.622
	OU												.645
12. OU L 50	RE												
	LE												
	OU												

Table 31a.- Table of Means and Standard Deviations-
Near Point of Accommodation Decrement

		1	2	3	4	5	6
Means	RE	2.86	2.65	1.81	2.54	1.79	1.79
	LE	1.58	1.95	1.35	1.89	2.81	2.54
	OU	1.58	1.89	1.84	1.84	1.33	1.39
S.D.	RE	3.43	3.74	3.29	3.50	2.97	2.93
	LE	2.88	3.08	3.19	3.12	3.65	3.22
	OU	2.71	3.07	3.30	3.01	2.70	2.74

		7	8	9	10	11	12
Means	RE	1.95	1.89	1.86	1.35	1.98	1.67
	LE	2.25	2.44	2.11	1.54	1.86	1.81
	OU	1.63	1.84	2.84	2.00	2.61	2.56
S.D.	RE	3.24	2.97	3.05	3.15	3.14	3.02
	LE	3.39	3.40	3.26	3.21	3.10	3.14
	OU	3.20	2.84	3.98	3.18	3.69	3.56

Summary and Conclusions

This is the second of a series of reports of a research program based on twelve experiments using the Berens ophthalmic ergograph. The subjects tested were 57 civilian subjects, ranging in age from 9 to 54 years. The design and experimental procedure have been described in detail. From evidence presented, the following points have been developed.

1. Near point of accommodation decrements were found to be statistically significant in three age groupings (over 30, 15-30, and 9-14), as well as for the total group.

2. Initial near point of accommodation increases with age. Correlations with age are .609, .630, and .608 for RE, LE, OU.

3. Variability within the group in accommodative power increases with age. Variability within the individual in accommodative power also increases with age.

4. Accommodation fatigue (meaning near point decrement) increases with age. Correlation of NPA_D (total) with age is .285.

5. Accommodation fatigue is related inversely to accommodation power. Average correlation of NPA_I with NPA_D is about .37 (see Table 16).

6. Accommodation fatigue was found to be unrelated to refractive error under cycloplegic; in these experiments all subjects wore normal correction.

7. Accommodation and muscle balance measures appear to be unrelated. (See Table 18.)

8. Kymograph tracings of ergograph performance correlate highly with decrement measures computed from initial and final measures taken independently before and after each ergograph run. (See Table 19.)

9. The amount of time a subject was able to continue to pursue visually the ergograph test object appears to be a valid index of fatigue. Time score varies inversely with near point decrement: correlation with NPA_D: RE -.553, LE -.554, OU -.564, Total -.572.

10. The interaction effect of ergograph exercise on the occluded eye, previously reported, was reanalyzed and verified with a statistical test of significance. (See Table 20.)

11. Lateral phorias, measured using Maddox rods at 25 cm. and 6 meters were converted into a continuous quantitative variable. Scores were computed by treating esophoria as minus, orthophoria as zero and exophoria as plus deviations, and adding 100 to each value. Thus scores below 100 represent esophoria, 100 equals orthophoria and over 100 exophoria.

12. Correlation of initial average phoria scores (both for near and distance) indicate that there is a tendency for originally existing phorias to be increased in the same direction following ergograph exercise. Correlations are: .354 (25 cm.) and .618 (6 meters) between initial phoria scores and derements. Analysis of individual cases (see Tables 23 and 24) indicates this tendency both for esophoria and for exophoria cases and suggests that it occurs more pronouncedly in extreme cases. Adequate ophthalmic examination data are not available to explain this important finding.

13. No relation was found between muscle balance measures and refractive error under cycloplegic. As noted above for near point of accommodation, normal correction was worn by all subjects.

14. Although a variation of initial near points of accommodation was found in relation to illumination, no evidence of any effect of illumination on accommodation fatigue was found.

15. No evidence of a differential effect of type of test object was found.

References

1. Berens, C. and Sells, S.B.: Experimental Studies of Fatigue of Accommodation, I. Arch. Ophth., 31: 148-159 (Feb.) 1944.

2. Ferree, C.E. and Rand, G.: Intensity of Light in Relation to the Near Point and the Apparent Range of Accommodation. American Journal of Ophthalmology, V. 18, No. 4, (April) 1935.

DISCUSSION:

Dr. Sloan asked Dr. Sells exactly how the difficulty of the accommodative task was equated for the various subjects used.

Dr. Sells reported that the equating was accomplished by adding 20 mm. distance to the near point of accommodation of each subject.

Dr. Sloan pointed out that this procedure involved a linear adjustment of the difficulty rather than a dioptric adjustment which would represent equal accommodative difficulty.

Dr. Sells suggested that equating difficulty in terms of diopters would be a desirable improvement of the technique which could well be made.

Dr. Scobee asked how the subjects were refracted.

Dr. Berens reported that refraction was made by cycloplegic examination and that the near point of accommodation was also measured under cycloplegia. He stated that the subjects were given their full correction without "crowding".

Dr. Sloan remarked that it was difficult to interpret the results of the data evaluation since the analysis was not made in terms of diopters but rather in terms of linear differences in distance.

Dr. Sells agreed that a dioptric evaluation of the data would have been preferable. He stated, however, that the statistically significant results in the experiment would be minimized rather than maximized by the method of treatment. He stated that, although the statistical analysis performed indicated a low probability of a chance difference in a direction found, no estimate was possible of the significance of a difference of a given size.

Dr. Scobee reported interest in the phoria increase obtained with exercise. He stated that the Russians are reporting that all patients exhibit increased esophoria with exercise, regardless of the direction of their original phoria.

Dr. Berens expressed his belief that the phorias, either eso or exo, will become worse after exercise on the ergophthalmograph.

Commander Farnsworth asked if exercise led to greater variability of the measured phorias.

Dr. Sells reported that he had not analyzed the data with that point in mind.

MINUTES AND PROCEEDINGS OF THE MEETING OF THE

ARMED FORCES-NRC VISION COMMITTEE SUBCOMMITTEE ON VISUAL STANDARDS

September 20, 1948, Washington, D.C.

The following persons were present:

Dr. Richard G. Scobee, Chairman
Dr. Conrad C. Berens
Dr. H. Richard Blackwell
Dr. E. J. Brundage
Lt. Comdr. Ellsworth B. Cook
Lt. Comdr. Dean Farnsworth
Dr. David L. Freeman
Dr. Henry A. Imus
Mr. Morris Leikind
Dr. Walter Miles
Major Robert A. Patterson
Dr. Stephen L. Post
Dr. W. M. Rowland
Captain C. W. Shilling
Dr. L. L. Sloan
Dr. John H. Sulzman
Dr. W. S. Verplanck
Miss Lorraine Wallach
Dr. B. J. Wolpaw

VISUAL TESTING TERMINOLOGY

The first item on the agenda was presented by Captain Shilling. Captain Shilling asked whether the Subcommittee would recommend the usage of the symbols O.D., O.S., and O.U., or the designations Right, Left, and Both, to refer to the eyes tested during visual examination. After some discussion of the present usage in the Navy and the Air Forces, the following recommendation was approved for transmittal to cognizant authorities in the Armed Forces:

RECOMMENDED THAT: regardless of present usage, the symbols V.R., V.L., and B. or the terms Right, Left, and Both, be used to designate vision in the right eye, vision in the left eye, and vision in both eyes, respectively, in connection with visual testing in the Armed Services.

VISUAL ACUITY CHART SPECIFICATION

The second item on the agenda was a discussion of the conclusions to be drawn from Report PRS #742, "Studies in Visual Acuity", issued by the Adjutant General's Office. Dr. Scobee called upon Dr. Wolpaw to present his opinion as to the conclusions to be drawn from the study.

Dr. Wolpaw began by calling the Subcommittee's attention to the fact that the AGO program was initiated on September 21, 1945. He expressed the belief that because of the long time since the beginning of the program, some sort of definitive recommendation should be made as to the conclusions reached. He pointed out that at the time of beginning the study, there was no discussion in the Services of a visual screening device. At that time, the obvious variability in visual test scores at different stations at different times was thought to be the result of poor charts. Dr. Wolpaw stated his belief that the AGO study indicates convincingly that the variability encountered in Service use was the result of variability in test procedures rather than variability in test charts.

Dr. Wolpaw expressed his belief that the AGO study indicated that there was insufficient difference between the various tests of visual acuity to warrant a change from the present Snellen Chart. Especially in view of the anticipated change to visual screening devices in the near future, it seemed to Dr. Wolpaw that a change now to other test charts would be ill-advised. Dr. Wolpaw suggested that since the study points to faulty administration of visual tests under Service conditions, the Subcommittee might well consider steps to improve test administration.

Dr. Scobee next asked Lt. Commander Farnsworth to express his opinion concerning the conclusion to be drawn from the AGO study.

Commander Farnsworth expressed his belief that there could be no doubt from the AGO studies that the checkerboard-type of chart is superior to other charts for testing visual acuity under laboratory conditions. He expressed agreement with Dr. Wolpaw, however, that the additional reliability of the checkerboard type test under laboratory conditions is not sufficient to justify recommendation of a change to these charts when use is to be restricted to the mass administration circumstances encountered in the Services.

Commander Farnsworth stated his belief that a letter-type chart should be used in the Services. He added, however, that he was not satisfied with the Snellen nor with any of the other letter charts now available. He pointed out that the Snellen chart is actually produced by groupings of series of blocks which are in themselves not unlike the checkerboard test squares. He indicated his preference for a letter chart made of thin strokes to simulate a line-resolution type test. Commander Farnsworth reported that he had in fact constructed a line-resolution letter chart, but that present difficulties of reproduction do not permit its use in mass testing at the present time. In conclusion, Commander Farnsworth reaffirmed his conviction that a letter chart should be used at the present time.

Dr. Scobee remarked that it should be possible to construct a better letter chart than the presently available charts, based upon the information uncovered in the AGO study. He expressed his belief, however, that an immediate recommendation was necessary from the Subcommittee concerning the kind of visual acuity tests to be used in the Services. Dr. Scobee believed that improvement of letter charts was a long process, which, therefore, should not prejudice the present recommendation.

Dr. Scobee asked Dr. Sloan to comment upon the conclusions to be drawn from the AGO study.

Dr. Sloan expressed agreement with Dr. Wolpaw that in general the AGO study indicated insufficient grounds for recommending a change from the present Army Snellen chart. Dr. Sloan commented on the difficulty of getting letter items of equal difficulty. She pointed out, however, that line resolution and checkerboard tests are not without objections. Patients with astigmatic error, in particular,

give anomalous results on these latter tests, to determine acuity in the presence of undetected refractive error. She remarked that proper identification of the checkerboard or line resolution type tests is possible with poor acuity, when astigmatic errors are present. Dr. Sloan concluded that perhaps the Landolt C would be the ideal test item. She pointed out that the Landolt rings are reliable and have equal difficulty.

Dr. Scobee next called upon Lt. Commander Cook for comments.

Commander Cook expressed his belief that the discussions had centered upon the wrong problem. The various discussants had concluded that the absence of differences in reliability between the various test charts indicated no marked advantage of any one test. Commander Cook suggested that instead of the reliability figures, the factor analysis data should be the chief criterion of desirability of the various tests. Commander Cook suggested that the first question the Subcommittee should ask itself is what is to be measured with visual acuity tests. The factor analysis indicated the presence of at least four factors. Various of the charts showed high purity on various of the factors. Commander Cook expressed his belief that the factor called retinal resolution is the principle variable which visual acuity tests in the Services aim to measure. He pointed out that if this assumption is granted, it is shown from the AGO study that the checkerboard tests have the highest factorial purity, accounting for more than 80% of the total variance.

Commander Cook pointed out that the letter tests indicate that only 64% of the variance is accounted for by the retinal resolution factor. Commander Cook expressed his belief that the contamination of the acuity tests by factors other than the factor called retinal resolution should be the critical point in the decision on a visual acuity test object. He reiterated his belief that checkerboard tests should be recommended on the basis of the AGO study.

Dr. Sloan commented on Commander Cook's interpretation of the results of the AGO study. She pointed out that factorial uniqueness is not necessarily the sole criterion of validity. To illustrate her reasoning she quoted from Thurstone. Thurstone attacked the prevalent view that uncorrelated factors are the only meaningful ones. She suggested that the contamination of the letter charts did not indicate that these charts did not measure meaningful visual capacities.

Dr. Scobee reminded the group that the names applied to the various factors should be scrutinized with care since naming the factors is not a statistical procedure but relies instead upon the good sense of the experimenter.

Dr. Blackwell remarked upon the fact that the two tests which were originally designed to measure brightness discrimination (quadrant contrast and dot contrast) showed significant loadings on the factor designated "retinal resolution". He suggested that the factor labeled "retinal resolution" is actually a resultant of two factors, a sharpness of the retinal image, and the sensitivity of the retina to small changes in brightness. Dr. Blackwell expressed his belief that only if retinal resolution were thought to be a composite of these two effects could the factor loadings obtained with the large objects in the brightness discrimination tests be explained. He suggested that it was unreasonable to expect a purely refractive effectto vary the discriminability of large objects. In support of this belief, Dr. Blackwell reported some recent experiments in which the presence of large objects was detected under conditions very similar to those encountered in the brightness discrimination tests. Blurredness of the large test objects was deliberately introduced over a very wide range with no change in the detection threshold. Such a result indicates that refractive errors would not produce a change in the scores

obtained on the brightness discrimination tests. This is equivalent to assuming that some factor other than refractive condition must be included in the factor designated "retinal resolution". Dr. Blackwell expressed his belief that if retinal resolution is indeed a composite of effects of refractive error and retinal sensitivity, that tests having high purity on this factor would be the most desirable for general use.

Dr. Scobee pointed to the data collected by AGO concerning the preference of examinees for the various tests administered to them, indicating their general preference for the letter test charts. He felt that examinee preferences was a serious consideration.

Dr. Berens expressed his agreement with Dr. Scobee on this point.

Dr. Wolpaw returned to Dr. Sloan's suggestion that the Landolt C be used as a test object, asking Dr. Sloan if she believed the Landolt C results would differ significantly with those of the Snellen chart.

Dr. Sloan expressed her general belief that the differences would be small and that she would be satisfied to standardize on the Snellen chart. She expressed again her belief, however, that there is a definite advantage in favor of the Landolt ring object since problems of memorization are virtually eliminated.

Dr. Rowland pointed out that Landolt rings should not be presented in long rows since the subject very readily becomes confused. He suggested that if a broken ring test object were adopted, it would have to be grouped into 4's or 5's.

Dr. Miles asked the group to consider the basic philosophy of visual acuity testing. He suggested that military acuity testing was designed to measure a capacity closely related to the use of the eyes in the military situation. Dr. Miles expressed his belief that the military services are primarily interested in the detection of objects rather than the recognition of objects. When the letter chart or a dot test, representing high contrast objects, are used, Dr. Miles expressed the belief that the wrong visual capacity was being tested. Dr. Miles expressed his belief that the detection aspect of human vision and the segregation aspect, in which objects must be differentiated from the general background, are both well tested by the checkerboard type test.

Dr. Scobee expressed agreement with Dr. Miles that in many military applications, detection rather than recognition is demanded. He expressed his belief, however, that military tasks call for peripheral vision when detection tasks are assigned because of the necessity for search. At the other end of the scale, military tasks require reading or other types of recognition. Dr. Scobee believed that the checkerboard type object measures neither extreme, and therefore represents a somewhat irrelevant type of test.

Commander Farnsworth suggested that the broken circle test object does not measure what people normally believe. He pointed out that observers do not in practice distinguish a break in the circle, but rather distinguish a little flattening or other change in the target object.

Commander Farnsworth pointed out that since this was the case, training in the type of change to be expected with Landolt C target objects can account for considerable variation in the score obtained.

Dr. Blackwell suggested that one factor which has not been discussed in interpreting the results of the AGO studies is the factor of forced discrimination which is utilized in some of the visual acuity tests. Laboratory investigations of the fixed discrimination kind of judgments revealed that they appear to be relatively unaffected by learning factors. If this is true, it might suggest the desirability of selecting a test in which the subjects were forced to discriminate to eliminate initial differences in ability to interpret letters, or interpret subtle changes in Landolt ring test objects. Dr. Blackwell suggested that perhaps the dot variable size test suggested itself as the most desirable test. This test includes the forced discrimination factor. It has as high loadings on the factor designated retinal resolution as other tests. In addition, it offers minimum cues to examinees with astigmatism.

Commander Farnsworth objected that the dot variable size test does not eliminate spurious recognitions because of astigmatism, particularly at the threshold.

Dr. Blackwell agreed that astigmatism will blur the dot into a line, but pointed out that laboratory studies show that the elongating the stimulus will make it less visible rather than more visible. This is equivalent to stating that the most efficient use of physical energy is a square form rather than any other shape, which was the result of laboratory tests at Tiffany.

Dr. Sloan pointed out that astigmatism can be equalized in visual acuity testing by testing in two dimensions.

Both Comdr. Cook and Dr. Imus suggested the desirability of the illiterate E test. They pointed out that item difficulty is equivalent and that the test is reliable and unlearnable.

Dr. Wolpaw suggested that in spite of the many arguments brought forth by members of the Committee, the simple fact still remained that insufficient differences had been shown to exist in the AGO study to warrant the expenditure of tax-payers money to change presently available visual acuity charts.

Various members of the Subcommittee agreed with this general philosophy, but wished it to be perfectly plain that the AGO study pointed to the need for further research both to improve present test charts and to determine the visual capacities which are important in various military situations. In addition, it was pointed out that emphasis should be given to the idea that difficulties in test administration account for much of the variability in best results obtained with the Snellen chart. The following recommendation was approved by the Subcommittee for transmittal to the proper authorities.

RECOMMENDED THAT:* In view of the fact that PRS 742 of the AGO's office reveals no marked superiority of any test of visual acuity over the present Army Snellen test, it is recommended that that test be kept with the following proviso:

(1) That provision be made for adequate manufacturing tolerances.
(2) That great emphasis be placed on proper testing technique, as outlined in the Manual for Testing Visual Acuity.

* This recommendation was revised by the Vision Committee. See Discussion of Dr. Freeman's report, following)

> The AGO study revealed the presence of certain factors in visual acuity which can and should be the basis for further studies toward the goal of developing a more ideal test chart. Since it is recognized that this will take an indefinite period, recommendation No. 1 is suggested for the moment in the light of and with limitations of, present knowledge.

Night Vision Testing

Dr. Scobee turned to the next item on the agenda, consideration of the status of night vision testing.

Dr. Imus introduced Dr. William Berry who is a member of the staff of the Vision Committee Secretariat. At the present time Dr. Berry is located in Washington, D.C., preparing a critical review of the wartime literature on night Vision Testing. Dr. Berry presented the preliminary report which is reproduced below:

An analytical study of the dark adaptation investigations and the night vision testing program sponsored by the U.S.Armed Forces. Preliminary report.

The scope of this study, which was begun early in August, is the analysis of the reports of work done, and results obtained, in the rather large number of investigations carried on during the war years. The extraordinary strong practical interest in the subject of night visual efficiency brought about by the necessity of carrying on many activities of diverse sorts under conditions of low illumination is clearly indicated by the initiation of research projects by the several branches of the Armed Forces immediately following the outbreak of the war. The interest became intensified as time went on and is reflected in the numerous but relatively uncoordinated investigations carried on in different parts of the country.

The reports of the investigations are listed by title in the Bibliography of Visual Literature, edited by J. F. Fulton and Associates, covering the years 1939-1944., and in an unbound supplement covering the years 1945-1946.

The purpose of the study has been defined as follows; (1) to ascertain the contributions made by means of the investigations to the immediate and practical problems of selecting Armed Forces personnel with respect to night visual efficiency, (2) to make recommendations on the advisability, or otherwise, of projecting a testing program by means of adaptometers or similar devices, in the peace time activities and/or the activities of Armed Forces personnel in a future state of war.

In accordance with the terms of the project the writer has spent the last six or seven weeks in covering the reports which are immdiately available. To date it has not been possible to gain access to many of the reports listed in the Bibliography. In the nature of the case this is a preliminary paper since only a small sample of the material has been read and analyzed. It will be obvious that one of the major questions in an undertaking of this type is the procedure to be followed in condensing the material for presentation to those primarily concerned with the outcome. There is no one best method and a selection has to be made from the possible ones. For the purpose of this paper it was decided to extract from the re-

ports the quantitative data on the test-retest reliability of the several adaptometers used, the data on the intercorrelations of the tests with the instruments, and the data from validation studies of the instruments involving comparisons between test scores and scores on performance in outdoor situations under conditions of low illumination, or synthetic facsimiles of such conditions. The data available have been arranged in tabular form, tables 1, 2 and 3. Copies of the tables with the attached bibliography have been distributed. It is, of course, fully recognized that this method of presentation has the disadvantage of attenuating the reports of the investigations by the necessary omission ofmany details not susceptible to tabular arrangement. However, there may be an advantage in the method in that it brings together for immediate comparative inspection the most pertinent ingredients of the reports.

In table 1 are shown the reported correlation ratios of reliability of test-retests. The order of presentation in the table was determined by the sequence of index numbers of the reports listed in the Fulton Bibliography and is not necessarily chronological in order. Tables 2 and 3 show the intercorrelation ratios and the validation correlation ratios respectively. Before drawing any conclusions from the tables it may be in order to give some additional information taken from the reports where such seems to be relevant.

Reference 1. In this study the size of the test object which was a Landolt ring was varied, as were also the levels of illumination used. The authors stated that when test-retests are separated by a few days the correlations are .80 for 30 minute size test object; .82, .85, and .87 for the $37\frac{1}{2}$ minute size object; .76 for the 1 degree and .77 for the 2 degree size objects respectively. When tests are separated by an interval of 1 month the figures are .64, .63, .64 for the $37\frac{1}{2}$ minute object. The correlations between scores with different sizes and at various levels of illuminations are said to be significant.

Reference 2. In this study there were 8 levels of illumination used, ranging from 5.3 to 3.55 log units in steps of .25 log units. The size of the test object was 2 degrees. It is stated that a large learning factor is indicated but no analytical details are given.

Reference 3. In this investigation the instruments used were the Eastman adaptometer, models 1 and 2; the Hecht Shlaer (NDRC model), the Johnson Foundation Luminous Plaque, and the Luckiesh Moss Low Contrast Test Chart. Through an error the correlation figures of the two latter instruments were omitted from the table. They are .61 and .81 for the Johnson Foundation Lum. Plaque and the Luckiesh Moss Chart respectively. All the correlations are said to be statistically significant with the exception of the one for the Hecht Shlaer (form perception). The Eastman model 1 is reliable even when intervals of 1 to 2 months occur between test and retests.

Reference 4. The data in this investigation were gathered from several sources and compiled by the author. It should be added that the correlation ratio for the Radium plaque night vision tester is .85 when N equals 34, as given in the table, but it is reported as .54 when N equals 200. The statement is made that two night vision tests are now available which are reliable and yield comparable scores. They are the Eastman, model 2, and the Radium plaque night vision tester.

Reference 5. The correlation figure given in the table is .79. This is between test 2 and test 4. No figure is given for the other tests, but it is stated that the mean difference between test 1 and 2 is 3.72 and the mean difference between test 1 and 4 is 4.4. It is concluded that practice effect is greatest between the first and second test and subsequent tests are of little value.

Reference 6. The report from which the data in the table are taken is a comprehensive one covering in coniderable detail an entire series of studies, progressive in nature, and extending over a period of several months. Time does not permit of anything more than a drastic condensation of the material contained in the report. Beginning with a pilot model adaptometer designated NVX a series of modifications were made involving changes in such variables as the size and nature of the test objects, the source of illumination, the methods of varying the brightness levels for test purposes, the method of recording the responses of the subjects, etc. Each stage of the series has a designation such as is indicated in the table, e.g., ANVX and ANVT with numerals attached in each case. Apparently the instrument designated ANVT-15 was adopted as the official adaptometer for use by the Army Ground Forces. Many correlations and intercorrelations are given in the report and only a few could be extracted for inclusion in the table.

Reference 7. A variant of the ANVT was used in this study. It has a radium source of illumination and was designed for use in places where the other models were impracticable for one reason or other.

References 8 and 9. Two reports are included by title in the bibliography distributed although they are not represented in any of the tables. The omission is due to the fact the writer was unable to discover quantitative data of a kind comparable to those obtained from other reports. However since both studies were devoted to the characteristics and the use of several adaptometers brief excerpts may be quoted. In the study reported in 1943, listed as reference 8, there were several instruments used. The purpose of the investigation was to determine the proportions of the number of men failing a second test who had either passed a first test or had failed a first test. The study is detailed enough and it is unfortunate that the only part condensed enough to quote here is a table which shows that the Adactometer, the Navy Telesilhouette, the Hecht Shlaer R. C. N. model, and the Admiralty, Mark 1 are promising; the Rotating Telesilhouette and Miles 4 plaque are both unstable. In the study reported in 1942, listed as reference 9, the instruments used were the Hecht Shlaer model 2, the NDRC model 2, the miles 4 plaque and the Pensacola adaptometers. The report of the study is a massive one, some 63 pages in extent. The following are summary statements taken from it; (1), Test-retest scores on 47 men with the Hecht Shlaer, model 2, showed good reliability in the central portion of the data, no reliability at the extremes where it is most needed; (2), good reliability for selection of better-than-ave., and for superior subjects with the NDRC, model 2; (3), the Miles 4 plaque is consistently unsuccessful in use; (4), test-retest reliability of the Pensacola adaptometer is consistent.

Reference 11. The instruments used in this investigation were modified so as to be relatively comparable with respect to the size and nature of the test objects, the fixation points and the levels of illumination. The figures given in the table are for correlations between test 1 and test 2 (day 1 and day 2), for each instrument. Other correlation ratios are the following; pearson r .753, .808 and .814 between day 1 and the means of the scores on 4 days with the Hecht Shlaer, the Self Lum. Telesilhouette and the NDRC adaptometers in the order stated. The eta correlations for all subjects with complete data are .781, .727 and .778 for the same order of adaptometers. In view of the skewed nature of the distributions of the scores the eta correlations are no doubt more representative than the product moment. The author stated that all the instruments are satisfactorily reliable and the data would seem to indicate the variability of individuals is such as to preclude the obtaining of reliability coefficients much higher than .70.

Reference 13. The Adactometer is a device designed to test not only dark adaptation, but also visual acuity as well as recovery from a moderate degree of glare effect. The term adaptacuity, or as it sometimes appears, adacuity, refers to a score to which are contributed certain percentage values derived from the scores on the total number of letters read during the test, the time required for a defined level of partial recovery time and for the time required for a defined full recovery time. The Pearson correlation ratio for the performance defined as total letters read is given in the table as .901. The eta correlation for the same item is .94, and the eta correlation ratio for adaptacuity is .915.

In these investigations the data were analyzed by means of the chi square formula. The resultant figures are included in the tables for information, it being thoroughly understood that they are not directly comparable to the Pearson product moment or eta correlations taken from other investigations.

References 18 and 19 do not call for any special comment.

Reference 20. To the best of the writer's knowledge the title of this report has not been listed in the Fulton Bibliography, nor in the subsequent supplement issued. The authors stated that the Navy Radium Plaque does not give sufficiently consistent results to warrant its use as a selective device. A single test is not justified. The suggestion is made that if it is to be used for selection, all subjects should be given sufficient practice to reach their "level" or performance before being passed or failed.

Reference 21. This study also is apparently not listed in the Bibliography or its supplement. It is one of a series of 4 investigations to determine the effect of varying the distance from the subject to the test object in the Navy Radium Plaque test situation. The standard distance is 5 feet. The distributions of the scores on the several tests show a definite shift from a skewed piling up of high scores to a skewed piling up of low scores. At the distance 7 feet, the scores are approximately evened off throughout the distribution. The correlation ratio is highest for this distance. The author pointed out that the best spread of the scores appeared in this test and made the suggestion that the 7 foot distance be made the standard one instead of the 5 foot distance. He concluded that the 7 foot distance was found to be more useful and more reliable for the purpose of general night vision classification. The Navy Radium Plaque could be used at the 9 foot distance for the rapid selection of individuals with superior night vision.

Limited in number as are the studies presented in this paper and having a bearing on the question of reliability, there is even more limitation with respect to the intercorrelations between the several adaptometers. This is also the case in the matter of the validation of them by means of field tests, actual or synthetic. The following brief additions to the information contained in table 2 are offered.

Reference 10. The author stated that the correlations are not high, but indicate that the two tests are measuring the same function.

Reference 11. In this study the author concluded that the Self Luminous Telesilhouette and the NDRC intercorrelations are consistently higher than test-retest correlations of each instrument. It could be assumed that they measure the same variable, which undergoes day-to-day changes within the individual. The Hecht Shlaer does not correlate highly with the other two. Probable reasons are given. The Hecht Shlaer requires monocular vision, near fixation, the field is smaller, it uses violet light and the scores are less variable.

Reference 13. The correlations given in this study are either negative or are relatively low. It seems reasonable to say that the Self Luminous Telesilhouette and the Hecht Shlaer RCN model are not measuring the same function. The correlations between the Self Lum. Telesilhouette and the Adactometer are quite ambiguous in nature.

Reference 21. This study also indicates that Hecht Shlaer and the Navy Radium Plaque are not measuring the same thing.

The paucity of the material in table 3 is obvious. It was included simply for the record.

Summary.

1. Data drawn from reports of investigations of dark adaptation and night vision testing programs sponsored by the Armed Forces during the war years and, to a limited degree, subsequent to the war years have been presented.

2. Taking the data on the reliability, test-retest, of the several adaptometers used in the investigations as a basis, a tentative conclusion may be made that there is fair to good correlation shown. In view of the very limited amount of data available it would seem to be unwise to make a graded arrangement of the adaptometers in this respect at this point.

3. Conclusions of any nature on the matters of intercorrelations between the instruments, and the correlations between the instruments and field tests, are not warranted at this time.

Recommendation:

1. That the study be continued and a further report be made at a later time.

Table 1

Coefficients of reliability, test-retests, reported in studies of dark adaptation and night vision testing. U. S. Armed Forces. All coefficients are Pearson product moment correlations except where otherwise noted. References are to the bibliography attached.

Ref.	Adaptometer		Correlations	N
1.	AAF-Eastman Model 1.		From .76 to .87	
	" " "	1 month interval	" .63 " .64	
2.	AAF-Eastman Model 2.		.78	44
3.	AAF-Eastman Model 1.		Ave. corr. .88	24
	" " " "	1-2 mos. interval	From .58 to .76	24
	" " " "		Ave. corr. .68	24
	Hecht Shlaer Portable	(light)	" " .64	24
	" " "	(form)	" " .48	24
4.	AAF-Eastman Model 2	1° test object	.68	200
	" " " "	2° test object	.76	16
	Sch.Av.Med.Portable.SAM		.42	200
	AML Radium Plaque Night Vis.Tester.		.85	34
5.	AAF-Eastman		.79	85
6.	Army Night Vision Tester			
	ANVX 1		.83	100
	" 2		.82	312
	" 4		.92	70
	" 13		.87	98
	ANVT 15		.74	709
7.	ANVT 15		.91	490
	" R2 Radium plaque		.91	490
11.	Hecht Shlaer		.637	90
	" "	Eta Correlation	.765	90
	Self Lum.Telesilhouette		.669	90
	" " "	eta correlation	.572	90
	NDRC.Model IIA		.674	90
	" " "	eta correlation	.779	90
12.	NDRC.Model II		.77	19
13.	Adactometer	Total letters read	.901	108
	"	Partial recovery time	.556	108
	"	Total recovery time	.649	100
	"	" Adaptacuity "	.878	100
	Self Lum.Telesilhouette		.761	108
	Hecht Shlaer RCN Model		.636	108
14.	Navy Radium Plaque	Test$_{1,2}$. Chi square 61.2		202
		Test$_{2,3}$. Chi square 21.6		56
		Test$_{3,1}$. Chi square 102.3		56
		In each case P equals .00000		
15.	Miles 4 Plaque		.57	28
16.	Navy Radium Plaque	Chi square 2.93		134

Table 1 Continued.

Ref.	Adaptometer	Correlations	N
17.	Hecht Shlaer. RCN Model.	.422	150
	Tufts SDS	.190	150
	Clackface	.266	150
	Navy Radium Plaque 50% correct level. Chi square	24.172	150
	" " " 60% " " Chi square	31.162	150
	" " " 80% " " Chi square	33.699	150
	NDRC. Model III 1. 20% " " Chi square	7.393	150
	" " " 30% " " Chi square	16.365	150
	" " " 50% " " Chi square	16.206	150
18.	AML Radium Plaque Night Vision Tester.	From .54 to .89	
19.	Navy Radium Plaque Tetrachoric correlation	.65	115
	Modified Rostenberg (ANVT modified) " "	.66	115
	NMRI Portable. " "	.82	115
20.	Navy Radium Plaque.	.63	234
21.	Navy Radium Plaque.		
	(a) At 5 feet distance between subject and plaque	.56	124
	(b) " 6 feet " " " " "	.52	124
	(c) " 7 " " " " " "	.77	124
	(d) " 9 " " " " " "	.54	124

Table 2.

Coefficients of correlations between tests with various adaptometers reported in studies of dark adaptation and night vision testing. U. S. Armed Forces. All coefficients are Pearson product moment except where otherwise noted.

Ref.	Adaptometer	With	Correlations	N
4	AAF-Eastman.	AML Rad.Plaque N.V.T.	.78	16
	" "	" " " "	.82	66
10.	NDRC. Mod. III.	Miles 4 plaque 3.9 log units level	.60	21
	" " "	" " 3.6 " " "	.45	21
11.	NDRC. IIA.	Self Lum.Telesilhouette	.848	90
	" "	Hecht Shlaer	.449	90
	Hecht Shlaer	Self Lum.Telesilhouette	.413	90
13.	Self.Lum. Telesil.	Hecht Shlaer.RCN Model	-.555	108
	"	Adactometer. Total letters read	.476	108
	"	" Partial Recovery Time	-.452	108
	"	" Full Recovery Time	-.206	108
	"	" "Adaptacuity"	.385	108
17.	Hecht Shlaer	Clackface	.14	150
	" "	Tufts SDS	.04	150
	NDRC III	Navy Radium Plaque Chi square	19.86	150
19.	NMRI	Navy Radium Plaque Ave. tetrachoric	.65	115
	"	Modified Rostenberg " "	.72	115
	Navy Rad. Pl.	" " " "	.56	115

Table 2 Continued.

Ref.	Adaptometer	With	Correlations	N
21.	Hecht Shlaer	Navy Radium Plaque Average of tests at 5,6,7,9 feet between subject and the plaque	-.65	28

Table 3

Coefficients of correlation between tests with various adaptometers and tests of performance in field conditions under low illuminations. U. S. Armed Forces. All correlations are Pearson product moment.

Ref.	Adaptometer	With	Correlations	N
4.	AAF-Eastman	AMRL Field Test. (Identification of objects)	.83	16
	AML Radium Plaque N.V.T.	" " "	.64	16
6.	ANVT 15.	Field Test II		
	" "	Perception of objects	.73	48
	" "	Recognition " "	.71	48
13.	S.Lum. Tele- silhouette	Night lookout training (a) spotting objects on horizon	.074	
	" "	(b) objects identified	.043	
	Adactometer	Night lookout training		
	1.Total letters read.	(a) spotting objects	-.014	
		(b) objects identified	-.019	
	2. Adaptacuity	(a) spotting objects	-.074	
		(b) objects identified	-.055	
18.	AML Radium Plaque N.V.T.	Field Tests	.55 to .64	
22.	Navy Radium Plaque.	Field Test Combined perception and recognition scores	.51	56

BIBLIOGRAPHY

Numbers in parentheses are index numbers in Fulton, J.F. A Bibliography of Visual Literature, 1939-1944, and an unbound supplement.

1. E.A.Pinson and A.Chapanis. Form discriminations at low illuminations. U.S. AAF-ATSC. Aero med. lab. Feb 5 1943 (3813)

2. E.A.Pinson. Army Air Forces-Eastman night vision tester. Model 2. U.S. AAF-ATSC. Aero med. lab. March 11 1943 (3814)

3. E.A.Pinson and A.Chapanis. Tests of dark adaptation and night vision: their reliabilities and intercorrelations. U.S. AAF-ATSC. Aero med. lab. Dec 17 1943 (3816)

4. A.Chapanis. Night vision tests and the night testing program in the Army Air Forces. U.S. AAF-ATSC. Aero med. lab. July 1944 (3817)

5. P.R.McDonald. The reliability of the AAF night vision tester. U.S. School of aviation medicine. Nov 10 1943 (3831)

6. L.O.Rostenberg. Night vision studies. U.S. Field artillery school. Fort Sill. Feb 1944 (3834)

7. E.R.Henry. Camp Blanding study of night vision tests. U.S. ANOSRD Vision Committee. Minutes 3rd meeting. June 1944 (3842)

8. R.H.Peckham. Report on analysis of reliability of various adaptometers. U.S. Navy. NATB. Pensacola. April 1943 (3854)

9. R.H.Peckham. Tests of night vision. U.S.Navy. NATB. Pensacola. June 1942 (3855)

10. R.H.Lee and M.B.Fisher. Physical and physiological calibration of NDRC adaptometer Model III. U.S. Navy. NMRL June 1943. (3856)

11. W.S.Verplanck, et al. Comparative study of adaptometers. U.S.Navy. Submarine Base. New London. Dec 1942 (3861)

12. C.W.Shilling. Report on reliability test of NDRC adaptometer Model II. U.S.Navy. Submarine Base, New London. July 28 1942 (3862)

13. L.S.Beals and W.S.Verplanck. Further report on the testing of efficiency of night vision: comparative reliability and validity measures on the adaptometer and the self luminous telesilhouette adaptometer. U.S.Navy. Submarine Base, New London. Jan 1943 (3863)

14. W.S.Verplanck. A report on the night vision testing of 5750 men. U.S.Navy. Submarine Base, New London. Aug 12 1944 (3871)

15. W.S.Verplanck and D.T.Reed. A report on the test-retest reliability of the Milesfour-plaque adaptometer.
U.S.Navy. Submarine Base. New London. 1943 (3873)

16. W.S.Verplanck, G.R.Watson and D.T.Reed. Field tests of the radium plaque adaptometer.
U.S.Navy. Submarine Base. New London. Nov 26 1943 (3875)

17. C.H.Wedell. A study of the prediction of night lookout performance.
U.S. OSRD. Applied Psychology Panel. Mar 15 1944 (3959)

18. A.Chapanis and E.A.Pinson. A portable radium plaque night vision tester.
U.S. AAF-ATSC. Aero med. lab. Jan 1945 (4953)

19. R.H.Draeger, R.H.Lee and M.B.Fisher. Design, construction and preliminary evaluation of a portable multiple brightness radium plaque adaptometer.
U.S.Navy. NMRI August 11 1945 (4956)

20. J.B.Macmillan and B.Commoner. Field study of navy radium plaque adaptometer.
U.S.Navy. Corpus Christi. Texas. April 1944

21. S.Ross. An investigation of the effect of varying the test distance on radium plaque scores.
U.S.Navy. Bu. Med. and Sur. Project X-472. Report 2. May 1945.

22. S.Ross and C.G.Mueller. An investigation of the effect of varying the test distance on radium plaque scores.
U.S.Navy. Bu. Med. and Sur. Project X-472. Report 3. August 1945

DISCUSSION:

Dr. Scobee thanked Dr. Berry for his report and asked the Subcommittee for recommendations concerning Dr. Berry's proposal that the study be continued to completion. It was the unanimous recommendation of the Subcommittee that Dr. Berry complete the work.

Dr. Scobee asked the Subcommittee for a general discussion of night vision testing, oriented in terms of two considerations: (1) shall night vision testing as such be continued in the Armed Services; (2) if so, what instrument should be recommended.

Dr. Rowland commented upon three night vision testers with which he was especially familiar. An outline of his remarks is presented below:

Comments on <u>Three Night Vision Testers (AAF Eastman, SAM Portable and AML)</u>

1. <u>Reliability</u>. Not very high for any of the 3 instruments when subjects with pathologic night blindness are excluded. If within the normal group 3 classifications are made, i.e. inferior, satisfactory, and superior, no individuals will shift from inferior to superior or the reverse in a second test. Some will, however, change by one step, i.e. from inferior to satisfactory or the reverse, satisfactory to superior or the reverse.

The test-retest correlation coefficients for these night vision tests show a marked increase whenever one or more cases of extreme night blindness are added to the group. This merely confirms the general experience that all such tests are highly reliable as dichotomous tests which distinguish normal from pathologic night vision.

The Eastman test shows higher reliability with a 1° than with a 2° test target. This increase in reliability is at the expense of validity, since cone vision plays a part when small test objects and higher intensities are used.

2. <u>Durability</u>. In the form used during the war, the AAF Eastman Night Vision Tester was notably unsatisfactory. The AML tester has no moving parts to get out of order. The SAM Portable has proven durable in actual use. One instrument was found to be in good condition after more than 10,000 tests had been made at Laredo, Texas.

The powdered radium material used in the AML device (and in the Navy Plaque) is not as satisfactory as the painted radium plaques because of variation in brightness. (Information based on a Navy Report on radium materials).

3. <u>Practical efficiency in Field Use</u>. The AAF Eastman Test requires a standard source of electric current and is, therefore, not as suitable for field use as the instruments using self luminous targets. It also requires a light meter to check the brightness of the test field.

4. <u>Expense</u>. The Eastman instrument costs somewhere between $3500 and $5000. An improved instrument of this type, redesigned to eliminate some of its mechanical difficulties would perhaps cost more. The SAM and AML instruments could probably be built for about $100.00.

5. <u>Availability</u>. Only 13 Eastman testers were built during the war. If additional instruments of this type were built, complete redesign is necessary in order to eliminate the various sources of mechanical failure. Plans for construction of SAM and AML testers are available, so that additional instruments could be manufactured in a relatively short time. The present supply of both is inadequate to meet testing needs.

6. Ease of testing. (instructing personnel, type of and amount of space required). Instruction is easy in all 3 types. The Eastman test requires a space 15 by 30 feet. The SAM portable requires only sufficient space for 2 men to sit facing each other across a small table. The AML requires a space 4 by 16 feet. All tests require the same preliminary period of dark adaptation. In the Eastman test, 6-10 men are tested simultaneously. A period of 14 minutes is required for the test. The SAM instrument tests one man at a time, about 2 minutes per man. The AML probably is about the same as the SAM in this respect.

7. Additional comments. In the SAM test, the brightness level at which a test object of given size can be discriminated is measured. In the AML test only a single brightness level is provided, and the visual angle subtended by the test target is changed by varying its distance from the subject. In my opinion, the former method is preferable, because of the wider range of abilities tested and for other reasons.

Commander Farnsworth reported that at a recent meeting in Toronto, an international group had discussed the matter of night vision testing, and it seemed the consensus that no one was satisfied with night vision testing as practiced during the war years. Judging from reports received from Germany, even more work was done on the tests in Germany, but apparently with even less satisfactory results. Commander Farnsworth reported that it was the consensus of opinion that no satisfactory night vision test existed, and that considerable fundamental study is necessary before a satisfactory test can be developed. Reference was made to the studies now under way at the New London Submarine Base by Dr. F. L. Dimmick and associates.

Dr. Verplanck commented upon the generally unsatisfactory experience he had had in attempting to measure night vision, even under the especially well-controlled conditions at the New London Submarine Base. He expressed his belief that night vision tests have two purposes: (1) to eliminate the night blind; and (2) to permit selection of persons with exceptional night vision.

Dr. Verplanck reiterated his statement and that of Dr. Sloan, made at the last meeting of the full Committee, that the pathological night blind revealed themselves by complaints of Service experience. Verplanck expressed his belief that the differences in night vision ability among the "normal" population were not sufficiently great to justify attempts to select them since testing is so very difficult.

Dr. Verplanck emphasized again his belief that convincing validation studies have not been conducted for any tests of night vision. Special mention was made by Dr. Verplanck of presumed day to day variability in sensitivity. The report was made that some subjects are moderately stable, whereas others show enormous variations from day to day. It was Dr. Verplanck's belief that the unsatisfactory reliability of night vision testing is largely the result of day to day variability in sensitivity. In summary, Dr. Verplanck suggested that the best night vision test would involve sending a man into a dark room to pick up a book. The pathologically night blind would be evident with such a series of instructions. Considerable money would be saved by eliminating the apparently unsatisfactory night vision testing.

Dr. Miles commented on the question of the need for night vision testing, with reference to the question of whether testing or night vision training

should be adopted. He expressed his belief that if a choice had to be made, visual training should be selected. He felt that a 30-minute training period with the men divided into small groups would succeed in making efficient subsequent use of night vision ability.

Dr. Miles suggested that higher reliability in night vision testing might have been obtained if a short training period in night vision had preceded the testing of night vision. Under these circumstances, the men would have known what they were expected to do. In such a training session, the pathologically night blinds would easily identify themselves. In addition, in such a training session, men with exceptional night vision ability would be identified. Dr. Miles expressed his great interest in the problem of personnel with superior night vision, describing a few exceptional persons he had encountered in his night vision testing experience. He expressed his belief that discovery of these people and utilization of them in appropriate duties represented an important military consideration. Dr. Miles referred back to Dr. Verplanck's statement about validation of various night vision tests. He suggested that perhaps validation of night vision tests could be obtained in the night vision training to be given prior to any night vision testing. He felt that the night vision training situation was sufficiently like the situation on night duty to possess a priori validity.

Commander Farnsworth emphasized his belief that the inference made by Dr. Verplanck that lack of reliability of night vision tests was due to physiological variability might be unjustified. He suggested that perhaps the lack of reliability merely suggests that we have not yet developed a good test of night vision. He suggested that perhaps a definitive answer to this question will arise from the results of the present studies undertaken by Dr. Dimmick.

Dr. Scobee called for summary recommendations from the Subcommittee. The following recommendation was approved for transmittal to the appropriate authorities:

RECOMMENDED THAT: (1) The Subcommittee does not believe that mass testing of night vision is at present necessary.

(2) Any interest in night vision should be centered around night vision training rather than testing.

(3) Further study of night vision tests is desirable and should be undertaken.

On a suggestion from Captain Shilling, it was agreed that when the above recommendation is transmitted to appropriate authorities, it will be suggested that: (1) if night vision training is to be used, in spite of the recommendation of this group against it, it is suggested that testing should follow a brief training period and be made an integral part of the training period; (2) if night vision testing is to be undertaken, against the recommendations of the Subcommittee, some kind of plaque instrument is recommended. The particular plaque instrument to be used can apparently not be specified on the basis of present information.

Depth Perception Testing

Dr. Scobee asked the Subcommittee to consider a request from the Air Surgeon relative to the desirability of their standardizing on the Verhoeff Stereopter as a depth-perception testing device in the medical examination for flying.

After considerable discussion, the following recommendation was approved for transmittal to the Air Surgeon:*

> It is the opinion of the Subcommittee that the Verhoeff Stereopter is as suitable as any other test available for the measurement of depth perception in the selection of flying personnel. It is recognized that no present test of depth perception has been shown to have any correlation with ability to fly an airplane.

---

* This recommendation was revised by the Vision Committee. See Discussion of Dr. Freeman's report, following.

Visual Screening Device

Dr. Wolpaw asked the Chairman for permission to bring before the group a proposal in connection with Dr. Sloan's experimental studies of visual screening devices. Dr. Wolpaw made reference to the present renewal of inductions into the Armed Services, and asked whether it would not be desirable for visual screening devices to be installed at two induction stations. Dr. Wolpaw suggested that together with the Snellen tests being routinely given, tests could be made of the standard Orthorater and of any special screening device which Dr. Sloan plans to develop. He expressed his belief that such a field test would uncover difficulties in the screening devices which would perhaps not be uncovered in tests made under more favorable conditions.

Dr. Scobee remarked that screening devices have been in use in industry for some time, suggesting that such uses should have revealed significant difficulties. He agreed, however, that the induction situation possesses certain unique features.

Commander Farnsworth remarked that considerable data were available at the Submarine Base with the Ortho-rater, and suggested that perhaps these could be analyzed further if someone thought it desirable.

Dr. Imus reported that his group ran 30 or 40 thousand men through the Orthorater at Fort Lauderdale.

It was the consensus of opinion that in view of the large amount of field test data already available, no recommendation be made that Dr. Sloan set up visual screening places in connection with the present induction program.

A SUMMARY OF THE PROCEEDINGS OF THE

MEETING OF THE SUBCOMMITTEE ON VISUAL STANDARDS

The Subcommittee on Visual Standards met in Washington, D. C., on September 20, 1948. The following persons were present: Dr. Richard G. Scobee, Chairman; Dr. Conrad C. Berens; Dr. H. Richard Blackwell; Dr. E. J. Brundage; Lt. Comdr. Ellsworth B. Cook; Lt. Comdr. Dean Farnsworth; Dr. David M. Freeman; Dr. Henry A. Imus; Mr. Morris Leikind; Dr. Walter Miles; Major Robert A. Patterson; Mr. Stephen L. Post; Dr. W. M. Rowland; Captain C. W. Shilling; Dr. L. L. Sloan; Dr. John H. Sulzman; Dr. W. S. Verplanck; Miss Lorraine Wallach; and Dr. B. J. Wolpaw. The discussion will not be reported in full, but only summarized very briefly.

I. TERMINOLOGY

The Navy requested an opinion from the Subcommittee about the advisability of designating the eye under test for visual acuity as R and L for right and left eye. The practicing ophthalmologist has long used the V O.D. and V O.S. for the vision of the right and left eye respectively. Since many persons without medical training are testing vision throughout the Armed Forces, the consensus was that it was more practical to designate right, left and both eyes as R, L, and B respectively. This practice was recommended.

II. VISUAL ACUITY CHART SPECIFICATIONS

An analysis of the AGO PRS #742, Studies in Visual Acuity, was made with a view to making specific recommendations for charts to be used by the Armed Forces in testing visual acuity.

The report revealed two important items: (1) From the standpoint of reliability none of the charts tested was significantly better than the Snellen chart in use at the present time; (2) A factor analysis indicated weak spots in the letter charts which could probably be eliminated by suitable studies.

A majority of subjects tested indicated a definite preference for the letter charts. The Armed Forces are calling for a decision after more than $3\frac{1}{2}$ years of study. Additional studies to improve the letter charts would require relatively long periods of time. Emphasis in visual screening is being shifted to machine devices. For these reasons the consensus was that the Snellen chart now in use should be retained for the present with the following stipulations: (1) that provision be made for adequate manufacturing tolerances and that these be carefully observed; (2) that great emphasis be placed on proper testing technique as outlined in the Manual for Testing Visual Acuity.

It is recognized that there is definite need for further studies in the construction of visual acuity test charts. Any such projects are to be encouraged.

III. NIGHT VISION TESTING

The discussion on this subject was opened by a preliminary report of Dr. William Berry who is making an analytic study of the literature on night vision.

Various members of the Subcommittee who had had the widest experience in night vision testing during the past war were asked for their views on the matter. There was unanimous agreement that none of the present night vision tests available were suitable and that no performance level had been, or could be, set for use as a criterion for pass-fail.

The percentage of night blind individuals found during the last war was extremely small -- almost negligible. Practically all of these individuals could have been detected without the use of night vision tests solely on a basis of their performance under conditions of dim illumination.

The night vision training programs instituted toward the end of World War II produced an obvious and marked improvement in performance of individuals at scotopic levels of illumination.

The consensus was that great emphasis be placed on night vision training to the practical exclusion of night vision testing. Night blind individuals could probably be detected easily during a course of night vision training.

If the Surgeons General believe it imperative to use some test for night vision, despite the recommendation above, it is suggested that testing follow a brief training period and that some kind of plaque be used. The particular plaque to be used cannot be accurately specified on the basis of present information.

IV. DEPTH PERCEPTION TESTING

The Air Surgeon has requested an opinion relative to the desirability of use of the Verhoeff Stereopter to replace the Howard-Dolman test.

It is the opinion of the Subcommittee that the Verhoeff Stereopter is as suitable as any other test available for the measurement of depth perception in the selection of flying personnel. Ease of adequate maintenance is in its favor. The fact that examinees with low grades of uncorrected myopia could pass the Verhoeff, but not the Howard-Dolman, must be recognized. It should be remembered that no present test of depth perception has been proved to have any correlation with ability to fly an aeroplane.

Respectfully submitted,

David M. Freeman, M. D.

DISCUSSION:

Dr. Andrews asked whether the Subcommittee had any recommendations to make concerning the testing of color vision.

Dr. Freeman answered in the negative, and remarked that color vision testing is under the provisions of the Vision Committee Subcommittee on Color Vision.

Dr. Sells asked whether any steps have been taken to validate the standards of visual selection for air crews.

Dr. Scobee reported that so far as he knew no steps were being taken in this direction.

Dr. Imus remarked that it is necessary to establish job criteria before there can be a validation study of visual standards. He reported that establishment of job success criteria in the Navy has not as yet been undertaken.

Dr. Sells reported that he believed the Air Forces was going to proceed in the direction of specifying job success criteria.

Captain Shilling expressed his firm conviction in the great need for comprehensive job analysis of military specialties. He suggested that immediate steps be taken to get the job started. He suggested that the Vision Committee make a recommendation relevant to the importance of such job success criteria.

Colonel Lowery reported that the Army Ground Forces has been working on such a job analysis.

When asked by Captain Shilling to give more details about the study, Colonel Lowery reported that the plan called for testing of 50,000 men working at various Army jobs. The men were to be tested with the Ortho-rater and the Sight Screener. Efficiency ratings were to be obtained on each man. The purpose of the study was to see how poor the vision of various men could be without impairing their performance on the jobs tested.

Dr. Sells commented that efficiency ratings have been shown to be extremely unreliable. Further, he reported that if these ratings are reliable, they are not specific to visual aspects of the jobs rated.

Dr. Scobee remarked that one couldn't expect a man's general efficiency to depend upon vision since a man can compensate by being good at leadership or other aspects of the job.

Dr. Marquis pointed out that the important question concerns whether any clear relationship has been shown to exist between efficiency ratings and visual efficiency scores. He pointed out that in such a study one need not worry about the logic of the situation. If visual acuity turned out to be a good measure of leadership, then it could be used as such.

Colonel Lowery reported that the studies seemed to be getting positive results.

Dr. Marquis replied that this is all that matters.

Dr. Marquis asked whether the Subcommittee had any recommendation to make about selection of candidates with superior night vision.

Dr. Scobee replied that there was considerable discussion of this matter in the Subcommittee meeting, but that no action had been taken.

Dr. Rose reported that in Germany, separation of men into categories with respect to their night vision abilities had not proved fruitful.

A motion was made by Dr. Conrad Berens, which was approved by the Committee, in the form of the following recommendation:

RECOMMENDED THAT: The Services undertake a comprehensive analysis of the visual skills required for various specialized military tasks, to gether with adequate measures of proficiency in such tasks.

The Secretariat was instructed to forward this recommendation to the following:

1. The Air Surgeon, USAF
2. The Surgeon General, USA
3. The Chief of Bureau of Medicine & Surgery, Navy
4. The Chief of Naval Research
5. The Adjutant General, U.S. Army
6. Chief of Bureau of Personnel, Navy

Dr. Uhlaner commented on the recommendation of the Subcommittee that the AGO visual acuity study demonstrated no marked superiority of any tests to the Army Snellen test. He emphasized that the factor analysis indicated clearly the existence of several visual acuity factors which were present in larger or smaller amounts in various possible tests. The factor analysis indicated that several of the tests, such as the checkerboard test, were more factorially pure than the letter tests, including the Snellen test.

Dr. Uhlaner expressed his belief that too much credence had been placed by the Subcommittee in the preference data on various visual acuity tests. He stated his belief that these data were not very meaningful and that they were only included in the report as a matter of very incidental interest.

RECOMMENDATIONS PASSED BY THE SUBCOMMITTEE WERE PRESENTED TO THE VISION COMMITTEE FOR APPROVAL OR DISAPPROVAL

The Vision Committee approved the following recommendations, made by the Subcommittee, for transmittal to the appropriate authorities:

RECOMMENDED THAT: regardless of present usage, the symbols V.R., V.L., and V.B., or the terms Right, Left, and Both, be used to designate vision in the right eye, vision in the left eye, and vision in both eyes, respectively, in connection with visual testing in the Armed Services.

RECOMMENDED THAT: (1) The Subcommittee does not believe that mass testing of night vision is at present necessary.

(2) Any interest in night vision should be centered around night vision training rather than testing.

(3) Further study of night vision tests is desirable and should be undertaken.

As a result of discussion by the main Committee, the recommendations concerning visual acuity test charts and depth perception testing were rephrased and submitted to the Subcommitte by mail for approval. The recommendations were approved by the Subcommittee by letter ballot in the following form.

RECOMMENDED THAT: In view of the fact that PRS742 from the Adjutant General's office revealed the absence of significant differences in test-retest reliability between the present Army Snellen and other available tests, the use of the Army Snellen test be continued with the following provisos: (1) Provision must be made for adequate manufacturing tolerances; (2) Great emphasis must be placed on proper testing technique, as outlined in the Vision Committee Manual for Testing Visual Acuity.

The AGO study revealed that several separable visual acuity factors exist which may be included or excluded by the selection of various visual acuity tests. Analysis of these factors can and should be the basis for further studies toward the goal of developing more ideal visual acuity tests. When the comprehensive analysis of visual skills required for specialized military tasks, recommended by the Vision Committee, has been completed, appropriate visual acuity tests can perhaps be developed. Since it is recognized that the latter will take an indefinite period, the first recommendation contained herein is suggested for the moment in the light of, and with limitations of, present knowledge.

RECOMMENDED THAT: Because there is at present no conclusive evidence that tests of depth perception have high correlations with ability to fly aircraft, if the testing of depth perception is deemed desirable by the Services, in connection with the selection of flying personnel, in the opinion of the Subcommittee the Verhoeff Stereopter is as suitable as any other test available.

The Secretariat was also directed to make available to members of the Subcommittee copies of the Manual for Testing Visual Acuity. In accordance with this directive, a memorandum was mailed to all members, making available to them, upon request, the Manual for Testing Visual Acuity and also the Manual for Testing Heterophoria.

A COLOR SATURATION THRESHOLD METER

by
Heinz Haber, Ph. D.
and
Horst Fleck

It is a well known fact that the determination of the various thresholds of human sense organs provide almost the only means of gaining quantitative information as to their function. Insofar as color vision is concerned there are essentially two characteristic thresholds: (1) the color discrimination threshold and (2) the color saturation (and desaturation) threshold. The former has been the subject of numerous determinations by various authors. However, there are very few determinations of saturation threshold reported. This may be partly attributed to the fact that instruments which can measure this latter threshold must be designed exclusively for this purpose. On the other hand, instruments for determination of the color discrimination threshold are easily obtained by converting conventional spectroscopes or spectrographs in a comparatively simple manner.

An instrument designed to measure the threshold of color saturation and desaturation must meet the following requirements:

1. Two half fields must be presented to the observer's eye, separated by a line of the utmost fineness, preferably the edge of a prism.

2. The first half field must be illuminated by light composed of a mixture of daylight and colored light (preferably monochromatic). The ratio of intensity of the two component lights must be changeable between the limits $0 \leq \frac{I_d}{I_c} \leq \infty$. The combined intensity of the mixed light must be measurably changeable. The color of the colored component must be changeable.

3. The second half field, serving as a comparison field, must be illuminated by daylight (color temperature between 5,500 and 6,000 degrees Centigrade). The intensity of this light must be measurably changeable.

Various suggestions and solutions concerning these requirements have been reported in the literature. Necessitated by the work on color vision conducted in this Institute, a color saturation threshold meter has been designed and constructed. The performance of this instrument is satisfactory and a brief description of this instrument is presented. (See Fig. 1)

Light is emitted by a light source S_1, traverses the lens L_1 and a daylight filter F_1 to form Part I of the light path. A Nicol prism N, mounted in a pitch circle is then traversed by the light which is thus rendered linearily polarized. A lamp S_3 and a telescope T with a prism P_7 attached to it, permit readings of the pitch circle to 2 minutes of arc by means of a vernier. The light now enters a natural calcite crystal C_1. According to the laws of double refraction the incident light gives rise to an ordinary and an extraordinary beam forming two images I_1 and I_2 of the filament of S_1 in the image plane of the lens (broken

line at F_C). The two images are not formed in exactly the same plane due to the difference of refractive indices for the ordinary and the extraordinary rays within the calcite crystal. This difference, however, is negligible. The lateral distance between the two images amounts to 6mm. The rays forming the image I_1 propagate further unobstructed, while the rays of image I_2 traverse a color filter F_c which can be exchanged at will. The rays of both images then are united again by means of a second calcite crystal C_2 of similar dimensions as C_1. The reunited light falls upon a ground glass G_1 which serves as an illuminant for the one half of a photometer head consisting of conventional elements (Fresnel rhomboid prisms P_3 and P_4, a flat roof prism to produce the field division, circular diaphragm D_3 and ocular O). The eye of the observer is located at E. The total amount of light entering the right half of the photometer head can be measurably controlled by means of a square Koehler diaphragm D_1.

In accordance with the foregoing description of the design, the effects of rotation of the Nicol prism N can be easily predicted. There will be a change in the intensity of the two images I_1 and I_2 which can be expressed by means of the laws of polarization associated with the phenomenon of double refraction. One has:

$$R = \frac{\cos^2 \phi}{Kc \sin^2 \phi} \qquad (1)$$

whence R indicates the ratio of the daylight and the colored image, k_c represents the transmission coefficient of the various color filters used and ϕ is the position angle of the Nicol read on the pitch circle after proper adjustment of the former. The total intensity of the reunited rays behind the second calcite crystal C_2 illuminating the one semicircle of the field of view varies as:

$$y = c\ [\cos^2 \phi + K_c \sin^2 \phi] \qquad (2)$$

whence c is a constant characterizing the light source L_1 and the properties of the daylight filter F_1.

Obviously the condition 1 and 2, as outlined in the introduction are fulfilled.

Part II of the light path leads through two totally reflecting prisms P_1 and P_2 and traverses the daylight filter F_2. The lens L_2 forms an image of the filament at the point I_3 and is adjusted so that the diverging rays behind the image form a light patch on the ground glass G_2 about equal in size and intensity to that produced on the ground glass G_1. G_2 equally serves as an illuminant for the second half of the photometer head after having passed the Koehler diaphragm D_2 controlling measurably the intensity of Part II of the light path.

In contrast to the light path II, light of the polarizing side of the instrument must transmit a total length of more than 120 mm through natural $CaCo_3$ crystals. Due to minute impurities of the otherwise flawless crystals a slight yellowish tint of the emerging light is noticeable when closely apposed to the pure daylight in the field of view of the instrument. In order to render both half fields undistinguishably equal, a third light source S_3 has been attached to the instrument. Light from this source passes a slit D_3 (controlling the intensity of the ray) and amber filter F_3. A prism P_6 throws the light upon the ground glass G_2. Manipulating the slit D_3 allows addition of proper amounts of yellowish light to the daylight emerging from the filter F_2 to match the crystal absorption.

Obviously condition 3 of the introduction is also fulfilled. There are two major disadvantages of the instrument:

1. The color filters used do not represent a simple wavelength, but a whole transmission band. Thus, in the position of the Nicol $\phi = 90^\circ$ the light produced does not exhibit a saturation of 1. A set of interference filters with sufficiently small half widths, however, could overcome this difficulty and render the instrument usable for measurements of color desaturation thresholds. At present, the instrument is used only for determinations of perception thresholds of colored light added to white light.

2. Eq (2) shows that the total intensity J of the light mixture is a function of the angle ϕ. It would be rendered constant by insertion of a neutral density filter at the image I_1 between the calcite crystals; the transmission coefficients of such filters, reduced to the sensitivity of the cones, must match the ones of the respective color filters F_c. (This would multiply the term $\cos^2\phi$ in (2) by k_c and yield $J = c\ k_c =$ constant.) A more powerful light source and procurement of neutral density filters of proper transmission coefficients would eliminate this difficulty. The instrument is used in the range between $\phi = 0^\circ$ and $\phi = 25^\circ$ exclusively making permissable the disregard of the variation of J within certain limits, since the function $\cos^2\phi$ changes slowly in this range.

The light output of the polarizing side of the instrument has been measured by means of a Filter-Photonelement by Dressler, adapted to the sensitivity of the cones. Three series of measurements were made through the range $\phi = 0^\circ$ to $\phi = 90^\circ$ in steps of $\Delta\phi = 5^\circ$. (1) Total output without filter F_c (representing $J = c\,[\cos^2\phi + \sin^2\phi]$); (2) Output with image I_2 blacked out (representing $J = c \cdot \sin^2\phi$); (3) Output with image I_1 blacked out (representing $J = c \cdot \sin^2\phi$). The results are in agreement with the theoretical values well within the limits of the measuring errors. These amount to about 3% almost entirely attributable to changes in the voltage of the city supply lines feeding the light source L_1. This is to be corrected by use of batteries.

The perception threshold of color added to white light usually is expressed in terms of:

$$T = \frac{Ic}{Iw + Ic} \qquad (3)$$

in which I_W and I_C are the intensities of the white and the colored light, respectively. Obviously from the design of the instrument the following expression for T holds true:

$$T = \frac{K_c \sin^2 \phi}{\cos^2 \phi + K_c \sin^2 \phi} \tag{4}$$

Figure 2 shows graphs giving T as a function of ϕ with

$k_{red} = 0.061$

$k_{green} = 0.042$ of the respective filters used.

$k_{blue} = 0.041$

A color saturation threshold meter has been designed in which a gradually changeable mixture of white and colored light is produced by means of the phenomenon of double refraction. A ray of white light is split into two beams; one traversing a color filter. The two rays are then reunited so that a homogeneous mixture of white and colored light is obtained. Polarization of the two rays involved permits a measurable change in the ratio of intensities of both lights between limits of zero and infinity.

The instrument works satisfactorily in its present state, however, it needs two major improvements: (1) Instead of colored filters, interference filters producing monochromatic light should be used; (2) Application of neutral density filters of proper dimensions would provide constancy of the mixture's intensity throughout the measuring range; a condition which is only approximated for a limited range in the present instrument.

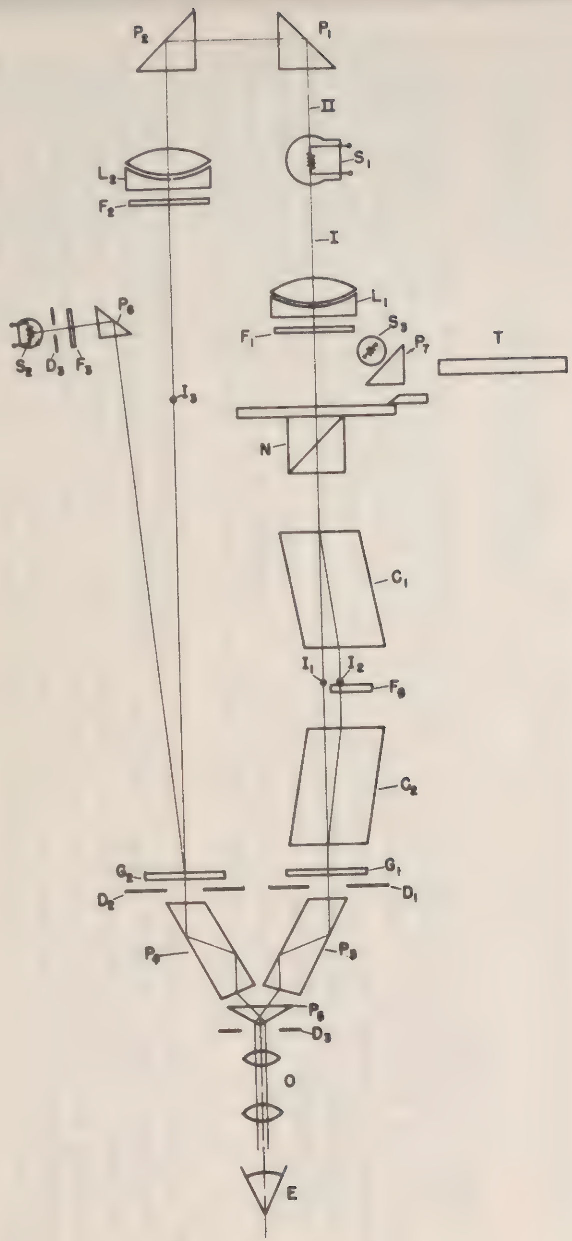


Figure 1

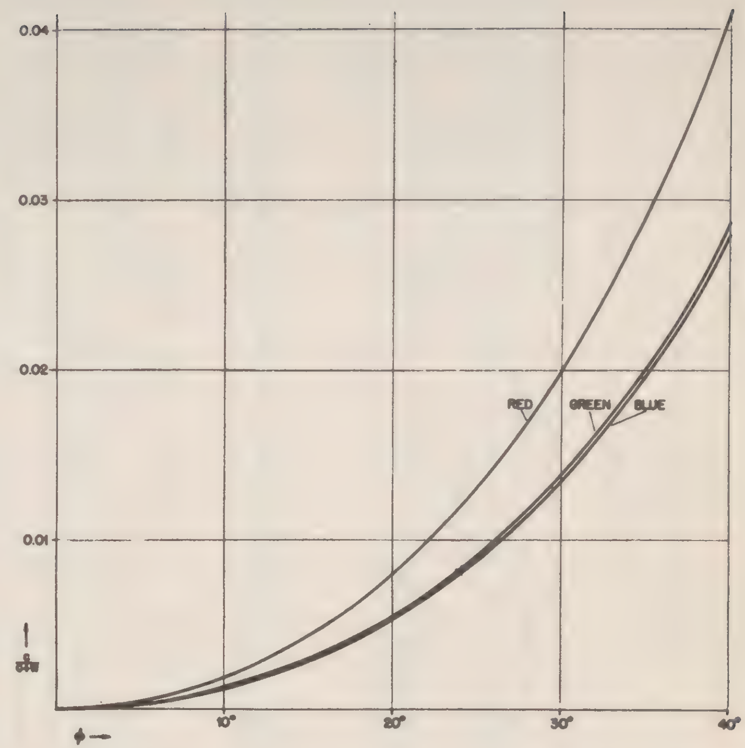


Figure 2

[redacted]

EFFECT OF VARIOUS FACTORS ON COLOR SATURATION THRESHOLDS

By
Ingeborg Schmidt, M.D.,
and
A. Bingel, M.D.

The color thresholds are a means by which the responsiveness of the color receptors of the eye can be measured quantitatively. Hence they may serve to measure the effect of various factors on color vision. In collaboration with Dr. Bingel the following factors important in aviation were to be investigated: effects of hypoxia, fatigue, alcohol and coffee. We wanted to determine whether these factors have a specific effect on one threshold or whether they affect color vision in toto and whether this effect occurs in the retina or the nervous centers.

Only a few works, some of them carried out inadequately, are published on the effect of these factors on the color thresholds.

Some authors discuss the question of whether the cones or the rods are more affected by oxygen lack. Since color vision is a function of cone vision, investigation of color thresholds is a means of studying the effect of hypoxia on the cones. On color threshold measurements in hypoxia only two papers by Russian authors are known. Of the one, by Belostockij and Vishnevskij, we know only the title. Vishnevskij and Zyrlin determined the color sensitivity with colored threshold test lights (color filters) and found that the red, green and blue sensitivity during dark adaptation begins to decrease above 5000 ft. Green and blue in particular appeared less saturated. These experiments are not very convincing. In the Berlin decompression chamber I made some tentative experiments and found a decreased red sensitivity beyond 13,000 ft., whereas green was not affected. I measured the color saturation threshold with spectral colors, the eye being bright adapted. These experiments, however, do not have any statistical significance.

Boehmig examined non-practiced individuals in fatigue after physical exercise and found a relative central scotoma for red and green.

As to the effect of alcohol, Zeiner-Henriksen after at least 30 cc of alcohol found a decreased red sensitivity.

Coffee seems to have an antagonistic effect to alcohol. Schultz found that coffee lowers the red threshold when taken as a beverage, not as caffeine. Woelfflin with a revolving color disc found a reduced red threshold 45 minutes after 4 cups of coffee, whereas the green threshold was not affected. Kravkov found the sensitivity for the spectral colors red-orange (590 mm) and green (530 mm) raised by 0.1 or 0.2 gram caffeinum purum. The effect appears 20 minutes after the caffeine is taken and persists for about 40 minutes. The thresholds were measured continually on the dark adapted eye.

We investigated the color saturation thresholds, because they can be determined more easily than the thresholds and are significant also. Colored light is added to a white field until the hue is just perceptible. The ratio of the brightness of colored light to the brightness of the white field plus colored light is a measure of the saturation threshold. We examined the thresholds for red, green and blue since these colors are of particular interest to the physiology of color vision.

[redacted]

Throughout the experiments the following conditions were observed:

1. Test subjects with normal color vision
2. Foveal size of the visual field 1.5°
3. Bright adaptation
4. Short periods of observation in order to eliminate color adaptation
5. Only appearance thresholds were checked
6. Change of colors without the examinees knowing it

Since the adjustment of the Color Treshold Meter, built by Haber and Fleck, could be accomplished only two weeks ago, we are not able to report definite findings. The results were not evaluated statistically. They can be used only as orientating material.

In numerous tests we found that it is necessary to train the subjects. At least four days of practising are required to stabilize the thresholds. The color saturation threshold is distinctly lower with a white comparison field than without it. This is evident from Table I, which gives mean values of 24 tests each, obtained with spectral color stimuli on the Nagel Anomaloscope.

Table I (Direct reading of color slit)

	Test Subject I			Test Subject II		
	RED	GREEN	BLUE	RED	GREEN	BLUE
With comparison field	1.1	1.8	2.1	1.4	0.8	1.4
Without comparison field	3.6	5.1	4.9	4.0	4.9	4.0

The basic requirement of any investigation is to obtain exact knowledge of the normal conditions first. By a great number of color saturation threshold measurements, e.g. taken at intervals of one hour during one day from 0800 to 2000, it was learned that the threshold ratio in some subjects is rather constant; in others it is more or less fluctuating. No characteristical diurnal rhythm was found, however.

Experiments with coffee indicated a slight lowering of all color thresholds, beginning after 20 minutes and lasting about $1\frac{1}{2}$ hours. It must now be determined whether the effect is due to a general increase in efficiency produced by coffee, or whether it affects the red-sensitive apparatus specifically. This has not yet been established because both the green and blue filters used contained some red. The experiments will be continued with filters with a narrower spectral transmission band.

30 ccm of 95% alcohol in 50 ccm water and 100 ccm of orange juice did not affect the color threshold of our trained persons.

Two persons were investigated 3 times with an oxygen-nitrogen mixture at a simulated altitude of 18,000 ft. The subjects breathed the mixture for 15 minutes. Five minutes after beginning we started the threshold measurements. From these results we cannot decide whether the hypoxia affects the color saturation thresholds.

The investigations will be continued and evaluated statistically.

DISCUSSION:

Dr. Dimmick commented that the problem of color saturation is of great interest to the Committee on small color differences of the Intersociety Color Council. He suggested that it would be wise for Dr. Schmidt to contact Dr. Judd of the I.S.C.C. Dr. Dimmick then asked Dr. Schmidt what was the condition of the surround that she used.

Dr. Schmidt reported that the surround was dark.

Dr. Dimmick reported that Dr. McAdam did his color saturation work with bright surrounds.

Dr. Dimmick asked Dr. Schmidt what psychophysical method she used for obtaining thresholds.

Dr. Schmidt replied that the subject adjusted the saturation to threshold. The subject was not aware of what color to expect and adjusted to just noticeably different and then named the color which was present.

Dr. Haber reported the development of a special type of interference filter which possesses very sharp cut-offs, which can be made to occur anywhere in the spectrum. Various members of the group expressed interest in the filters.

MOTION PARALLAX AS A FACTOR OF DEPTH PERCEPTION

by
H. W. Rose, M. D.

A good orientation in space is without doubt of great value in many activities. In military service it is especially valuable for range finder personnel and for pilots. Consequently, in most of the civilized states sufficient depth perception is a requirement for pilots. This seems to be incompatible with the findings of many authors who have tested pilots or cadets. For instance Kirschberg[1] tested 303 cadets with the Verhoeff apparatus. His results are given in Table 1 below.

TABLE 1

Depth Perception and Flying Ability
(303 Cadets Tested by Kirschberg)

Depth Perception	Finished Training	Eliminated fr Training	Total
Good	35 58.3%	25 41.7%	60
Average	98 56 %	77 44 %	175
Poor	42 61.8%	26 38.2%	68

The percentage of cadets eliminated from flying training is practically the same for the three groups; with good, average or poor depth perception.

There is another interesting argument which should be considered and that is the good flying ability of pilots who have lost one eye or who do not use one eye for reasons of amblyopia or high uncorrected anisometropia. Wiley Post is a famous example of this group. Jongbloed[2], Guilfoyle[3], Kyrieleis[4], Best[5], Lorenz[6] and this author[7] have reported such pilots and their good flying performance.

The contradiction of the requirements and the findings of the quoted authors can be solved. It must be kept in mind that depth perception is a highly complex process. Many factors contribute to it and are integrated in the final impression of space. Table 2 gives a list of some of these factors.

Table 2

Factors Involved in Depth Perception

Physiological diplopia
Convergence
Accommodation
Size of retinal image
Linear perspective
Motion parallax or successive parallax
Binocular or simultaneous parallax
Terrestrial association
Overlapping of contours
Lighting effects, shadows
Aerial perspective

For pilots, range finder personnel and drivers, insofar as the available literature shows, only the examination of the binocular or simultaneous parallax is in practical use. To call this an examination of depth perception is definitely misleading because only one factor of depth perception is tested. Thus the earlier mentioned discrepancies between tests of binocular (simultaneous parallax) and the ability to learn to fly might be explained by stating that for the depth perception of the pilot binocular parallax is either of no value or is not the main factor. The pilot does need depth perception, especially when landing an aircraft. He uses it to round out or level off at the right altitude.

With physiological diplopia only, orientation in space relative to fixation point can be expected. Binocular parallax was investigated and did not appear to be valuable for the pilot's depth perception. Convergence and accommodation are not very helpful beyond 6 m or 20 feet. For the use of the size of the retinal image, objects of known size must be available. Terrestrial association, linear perspective and overlapping of contours do not promise much help in the landing procedure. Aerial perspective is effective only at longer distances. But motion parallax is a factor which might be enhanced by the high speed of the aircraft and might be helpful for landing. In the available literature no method of measuring it and no results of such measurements were found.

It was necessary to build a special testing device for this factor.

The highest accuracy might be expected from an adaptation of Helmholtz's three rod apparatus to the testing of motion parallax. With vertical rods and horizontal motion of the apparatus, binocular parallax would have influenced the measurement and would have called for tests with only one eye. Measurement with one eye is of course possible when testing motion parallax. However, it seemed desirable to perform the test with both eyes open. Therefore, a vertical motion of a device of three horizontal rods was chosen. The upper and lower rods are fixed; the middle one can be moved back and forth. The vertical movement of the device covers 1 m (3 1/3 ft.). Seen from 3 m (10 feet), our usual test distance, that is 19° angular movement. The three rod device may be made to move up and down or move down only returning on the back side. The latter type of test was found be more difficult, so the results reported here are from only up and down movements.

Two types of tests were run. First, the time was measured which the examinee required to find out whether the middle rod was in the extreme anterior or the extreme posterior position. Those extreme positions are 30 mm from the plane of the fixed rods. In the second type of test the examinee tried to adjust the middle rod with a remote control to the same plane or to the same distance from him as the two fixed rods. These measurements were made while the three rod device was running up and down. The speed of the three rod device was 0.5 m per second or 9.5° per second. Besides several other groups, 123 cadets who were accepted for flying training after passing the regular 64* examination were tested 10 times with the motion parallax test and 10 times with the Howard-Dolman test. Table 3 shows the results of these tests.

TABLE 3

Howard-Dolman and Motion Parallax Tests
Average of 10 Tests Each Examinee

	123 Cadets before Training		102 Trained Cadets
Error with Howard-Dolman Test 20 ft.	14.77 mm	5.48"	13.82 mm
Same Corrected for 10 ft. (3 m)	3.68 mm		3.46 mm
Motion Parallax 3 m — Error	5.45 mm	$\frac{3"}{0.05\text{ Sec.}}$	5.51 mm
Time	2.48 Sec.		2.54 Sec.

Best average with Howard-Dolman test 3.1 mm or 1.21" error.
Best average with Motion Parallax test 1.9 mm or $\frac{1.05"}{0.05\text{ Sec.}}$ error.

*AR 40-110.

With the Howard-Dolman test the average error in setting the movable rod was 14.77 mm. One-fourth of this is 3.68 mm which would be the value for the Howard-Dolman test done at 10 ft. (3 m) distance instead of 20 ft. distance. This value might be directly compared with the absolute value of the error made with the motion parallax test. The average value of the latter error was 5.45 mm. The average time required to recognize the position of the middle rod in the extreme positions was 2.48 seconds.

The average of the parallactic angle for the Howard-Dolman test is 5.48". With the motion parallax test for each 1/20 of a time second or 2.5 cm of vertical motion the successive parallax is 3". The parallactic angles of both tests are near the value of vernier acuity. The best scores with each apparatus reach values which correspond to better than standard vernier acuity.

For the comparison with flying ability, the daily grading slips which the flight instructor fills out were checked for each student. After the solo flights began each instructor was requested to give his student a rating especially for his landing ability. The emphasis was on the leveling off at the right altitude. Five groups were formed, with group 1 the best and group 5 the worst. This rating was obtained for 102 students. For this group with the

motion parallax test the average time required to determine the position of the middle rod in the extreme position was 2.54 seconds. The average error was 5.51 mm. With the Howard-Dolman test the average error was 13.82 mm from the 20 ft. distance (this corresponds to 3.46 mm for 10 ft. distance). The average rating for landing ability was 3.33. The correlation coefficients for this set of measurements are given in Table 4. They were computed by Mr. Allyn W. Kimball, Department of Biometrics, School of Aviation Medicine.

TABLE 4

Correlation-Coefficients of Depth Perception Factors and Landing Ability

(The average of 10 measurements from each person with each test is used.)

Error Motion Parallax and Time Motion Parallax	+ 0.268
Error Motion Parallax and Error Howard-Dolman	- 0.028
Landing Ability and Time Motion Parallax	+ 0.215
Landing Ability and Error Motion Parallax	+ 0.258
Landing Ability and Error Howard-Dolman Test	+ 0.057

The correlation of motion parallax and Howard-Dolman test is a very low negative one virtually equal to zero. Obviously the ability of an individual to interpret simultaneous or binocular parallax does not give any indication as to his ability to interpret successive or motion parallax. Two truly different functions are tested. Time and error on the motion parallax test have fair correlation. In essential agreement with Kirschberg's findings, the correlation of landing ability and Howard-Dolman test is low. The outstanding result of this investigation is the comparatively much higher correlation of landing ability and the motion parallax test.

This result justifies the assumption that for the depth perception of the pilot in a landing aircraft not binocular parallax but motion parallax is the more important factor. Testing binocular parallax, though it should be valuable for range finder personnel, does not seem to have much value for the selection of pilots. Contrary to this, the motion parallax test promises better results in the selection of pilots. This is emphasized by the following results of the extreme cases. The ten best and ten worst subjects with the motion parallax test were compared as to their ratings for landing ability. From the ten best, one was eliminated for airsickness and one was transferred to another airfield. There were no eliminations for flying deficiency in the better group. From the ten worst subjects, four were eliminated for flying deficiencies. Poor landing ability was one of the foremost reasons given. The average rating for the remaining eight of the ten best was 2.6; the average rating for landing ability of the ten worst cases was 3.7.

TABLE 5

Average Results of Extreme Cases with Motion Parallax Test

		8 of 10 best subjects with motion parallax test	10 worst subjects with motion parallax test
Motion Parallax	error	2.6 mm	9.53 mm
	time	2.2 sec	3.7 sec
Rating Landing Ability		2.6	3.7
Howard-Dolman Test Error		19.5 mm	12.1 mm

The group with the better motion parallax test has the better landing ability rating. The measurements on the Howard-Dolman test are not in agreement with the rating in landing ability.

If motion parallax can be established as a valuable factor in landing an aircraft, then there are other points besides selection of pilots which should be considered. The training of this function may be possible by special motion pictures. The importance of motion parallax makes it easier to understand why student pilots and experienced flyers find it easier to estimate height above the ground when landing on grass compared to landing on asphalt. Similarly, landing near a group of hangars or other "obstacles" which are above the ground makes estimating the height above ground easier than landing on a big, completely flat field. The difficulty of landing on snow covered fields and on smooth water is partially explained by the lack of motion parallax. For training flights as well as for standard equipment of airfields and for emergency landings in the snow covered arctics special aids could be developed to make use of motion parallax effects. Further studies of this type and the construction of a smaller and simpler motion parallax tester are planned. Comparison of repeated examinations with the motion parallax tester and tests with one eye only have been finished and will be reported in the full report (which will be published under project Number 21-02-39 by the USAF School of Aviation Medicine).

1. Kirschberg, L. S. S., "Depth perception and flying ability," Arch. of Ophthal., 1946, XXVIII, 1000.

2. Joengbloed, J., "Landing carried out by experienced aviator with the use of one eye only," Acta Brev. Neerl. Physiol., 1935, V 123.

3. Guilfoyle, W. J. J., "Experiences of an uniocular pilot of aircraft," Trans. Ophthal. Soc., U. Kingd., 1937 LVII, 431.

4. Kyrieleis, W., "Einaeugige als Fluzeugfuehrer," Mitt. a.d. Gebiet d. Luftfahrtmedizin 1942, III.

5. Best, F., "Zur Pruefung der stereoskopischen Tiefensehschaerfe," Klin. Mobl. f. Augenheilkunde, 1944, CX 571.

6. Lorenz, R., "Refraktion und fliegerische Leistung," Luftfahrtmedizin, 1945, IX.

7. Rose, H. W., in "German Aviation Medicine," in printing.

DISCUSSION:

Dr. Ogle asked what the relation was between the least discriminable motion parallax difference and the total excursion of the pattern. He also asked what the effect of illumination of the pattern and of the surround had upon motion parallax acuity.

Dr. Rose reported that the effects of total excursion and illumination had not been determined.

Dr. Ogle suggested that Dr. Rose get in touch with Professor Graham who has been conducting a number of studies on various aspects of motion parallax.

The group adjourned for an examination of the motion parallax testing device which was set up in an adjoining laboratory room.

APPRAISAL OF THE CONSOLIDATED NIGHT VISION TESTER

by
Paul H. Ripple, 1st Lt., M.C.
USAF School of Aviation Medicine
Randolph Field, Texas

PRECIS

OBJECT

To make an appraisal of the Consolidated Night Vision Tester; to measure its ability to meet present night vision testing criteria and to correlate its performance by actual testing with the AAF Eastman and the Hecht-Shlaer Night Vision Testers. These two latter testers were selected because they are well known, accepted testers and are in use by the U.S. Air Force.

SUMMARY AND CONSLUSIONS:

The Consolidated Night Vision Tester meets some, but not all, of the criteria for a good night vision test. Its chief assets are:

a. Ability to test eight subjects simultaneously.

b. Radium plaque illumination which keeps the machine easily standardized and makes its light source durable.

c. Relative freedom from mechanical difficulties in the test itself. (This is not true of its scoring mechanism.)

Its chief disadvantages are:

a. Unevenness of illumination of the testing field because of a definite bright spot in the center of the testing field.

b. Lack of specifications for tracing cloth used as a diffusion screen.

c. Unavailability and high cost of the switchboard used for scoring. The fact that it does not score automatically, but requires the presence of an extra technician, is also considered a serious disadvantage.

d. Lack of a prescribed "random setting" routine. The average examiner's random settings show preference for certain positions.

e. Metal light baffles have no tactile identification markers and are therefore difficult to use in the dark.

f. The radium activated paint used is sensitive to exposure to light.

g. Abnormal distribution of test scores with a marked tendency for piling up at the difficult end of the test.

RECOMMENDATIONS:

That the Consolidated Night Vision Tester not be considered as an acceptable test for Air Force use in its present form. It does have some desirable features and if its defects can be eliminated, it may prove to be a satisfactory test.

APPRAISAL OF THE CONSOLIDATED NIGHT VISION TESTER

History - The Consolidated Night Vision Tester was developed at the Field Artillery School, Department of Gunnery, after extensive research on the problem of night vision testing. This work was under the direction of Major Lee O. Rostenberg.

Description - The Consolidated Night Vision Tester is a large metal box-type tester placed on a table. It presents a black two degree Landolt ring at twenty feet on a background of transilluminated tracing cloth. The illumination is supplied by a self-luminous radium plaque in a diffusion box. Intensity of illumination is varied by placing masking shields over the plaque; each shield containing a circular aperture of different size. In this way seven different levels of brightness are produced. (See Figure 1) The tracing cloth used was standard Air Force supply cloth. (Specification CC-C-531C)

Testing Procedure - Dark adapted subjects are seated behind their respective response stations at twenty feet from the tester. After an explanation of the test and night vision technique, an examiner presents several random settings of the Landolt ring by turning it to any of its eight possible positions. Any number of presentations can be made at each level of brightness. The brightness is decreased in steps by placing the graded shields over the radium plaque. The examinee attempts to set the indicator of his response station in the corresponding position for each setting and, if he is correct, will complete an electric circuit between the testing machine and a switchboard which will record his response. The scores are then tabulated from the switchboard.

Testing Procedure Used in This Project - Sixty men were tested on the Consolidated Night Vision Tester, AAF Eastman Night Vision Tester and the Hecht-Shlaer Night Vision Tester. The men were all young Air Force recruits (enlisted men). The six possible sequences in which the three tests could be given were replicated the same number of times. This made a total of 180 observations. Since no instructions were supplied with the test, the following procedure was used:

1. Prescribed random settings were used to insure an equal number of all the possible positions.

2. Subjects were dark adapted by wearing red goggles for twenty minutes and spending ten minutes in the dark.

3. Subjects were instructed as to the use of their response stations and other procedures of the test. In addition, they were given complete instructions in the technique of night vision.

4. Starting with the highest brightness (using the shield with the largest aperture) five random settings of the ring were presented. The bright-

ness was then reduced in steps till all the seven levels of brightness were used; presenting five settings at each level. This made a total of 35 presentations. The subjects were continually reminded to practice off-center vision and scanning during the testing.

5. The test was presented at twenty feet in a dark room

6. The following scoring procedure was used (the same relative scale as the Eastman Test). (See Figure 3)

0 - 17 unsatisfactory

18 - 31 satisfactory

32 - 35 superior

The Consolidated Tester in Relation to Criteria - The outline will follow a set of criteria which is believed consistent with the present concept of night vision testing.

Criteria 1. A night vision test should first and foremost disqualify the night blind individual. The Consolidated test apparently does this satisfactorily. It has a wide range of graded brightness levels with a lower level of about 3.5 log micro micro lamberts. Measurement was difficult because of a "hot spot" in the center, which made the brightness there considerably higher, while the periphery was less than 3.5 log micro micro lamberts. This phenomenon was also present with the higher brightnesses but was not as marked as with the low levels. The highest brightness is about 5.5 log micro micro lamberts. The steps in brightness are about .25 to .3 log micro micro lamberts. This range of brightnesses is very similar to that of the Eastman test.

In spite of the "hot spot" which probably accounted for the higher percentage of correct responses over the Eastman Test (62.2% and 55.5%), the lower levels of illumination may be adequate to rule out night blind individuals, but not definitely so. There was a fairly good correlation between the two tests in the failure group. Of the 18 men who failed the Consolidated Test, 13 also failed the Eastman, and of the 20 who failed the Eastman Test, 13 failed the Consolidated. There was not as good a comparison with the Hecht-Shlaer. None of the men who failed any of the three tests were superior on any of the others. Considering the learning factor, the above comparison of failure groups is good. (See Figure 4).

2. A night vision test should be discriminating. Due to the special needs of some services and forces, it is desirable to separate those who are superior in night vision. The Consolidated Test did only a fair job of this. As stated before, there was a higher percentage of correct responses over the Eastman, and what is more important, there was a tendency for piling up of scores at the difficult end of the test. The Consolidated Test could be made more difficult and thereby more discriminating if the "hot spot" was removed. This "hot spot" had a more noticeable effect at the lower levels of brightness. In spite of this disadvantage with the Consolidated, there was some correlation with the Eastman Test. Of four who were superior on the Consolidated, one was superior on the Eastman, and of two who were su-

perior on the Eastman, one was superior on the Consolidated. None of the sixty men tested who were superior on any test failed one of the other three. (See Figure 4)

3. A night vision test should be reliable. It should correlate well with other similar tests which have already been accepted. The Consolidated Night Vision Tester has a correlation of plus .658 with the Eastman Test. The confidence probability is 95% that the true correlation lies between .49 and .78, which is a fair correlation. Correlations of .7 to .8 are considered good. Neither test correlated well with the Hecht-Shlaer. The Consolidated Test had a correlation of plus .464 with a 95% probability that the true correlation lies between .24 and .64 while the Eastman and Hecht-Shlaer had a correlation of .448 and a range of .23 to .62 as a 95% probability. (See Figure 7)

4. A night vision test should have validity. No attempt was made to validate the Consolidated Test. It has fairly good face value as a night vision test, and the inventors have shown good validity for similar tests. The validation of any night vision test is very difficult.

5. A night vision test should be fairly rapid. The Consolidated Test takes about ten to fifteen minutes to administer, but since it tests eight men at a time, it can be considered a rapid test. The present method of scoring and the changing of masking shields is cumbersome in the dark. The test takes two men--one to run the machine and one to record scores. This latter man could be eliminated by putting counters on the response stations.

6. A night vision test should be easy to understand. The Consolidated Test is easy to understand. The subject is seated and at ease. The twenty foot testing distance makes scanning and off-center vision easier to accomplish and understand. The response station is simple and easy to understand, and by virtue of its pegs, it is superior to the response station on the Eastman Night Vision Tester which has practically no tactile clues. Instructions can be given to eight men at a time, as with the Eastman. The mass testing technique has two other advantages, (1) there is a competitive factor which makes most examinees try harder and (2) the personal relationship between examiner and examinee, as with small tests, is eliminated. This personal factor sometimes accounts for misleading results.

7. A night vision tester should be relatively inexpensive. The Consolidated Test falls between the $3,000 Eastman Night Vision Tester and the small portable $15.00 night vision tester. The exact cost of the entire Consolidated Testing Apparatus is about $1,200.

8. A night vision test should be durable and standardized. In this respect the Consolidated test is superior to the Eastman. The Eastman Test, while it is almost entirely automatic, requires skilled maintenance and vigilance of its standardized light source. The mechanism of the Consolidated, although somewhat cumbersome, is simple and its parts fairly durable. The use of a radium plaque as a source of illumination and thus a constant standardized brightness is the salient feature of the Consolidated test. It is because of the radium plaque that the small portable night vision tester has become a well accepted test.

9. Portability - This is a questionable criterion, but one to be considered. The small inexpensive portable tester has its salient feature here.

10. A night vision tester should measure form acuity at low levels of brightness. All the testers in popular use today do this. It is this criterion which gives the night vision tests their face value and any validity they may possess. If there are going to be any radical changes in the design of night vision testers, this criterion may have to be changed.

Disadvantages of the Consolidated Night Vision Tester and Recommendations

1. Presence of a "hot spot" in the center of the testing field.

   a. This hot spot is easily seen subjectively and is much more pronounced with the smaller apertures. It was also noted that, when the opening in the Landolt ring was on the left and the examiner also seated to the left, the "hot spot" was in line with the opening and greatly facilitated a correct response. The reverse was true when the opening was to the right.

   b. The "hot spot" was measured with the Schmidt Haensch photometer (using standard issue tracing cloth), and it was noted that there was a 38.8% loss of brightness in going from the center to an area just outside the Landolt ring, and a 53% loss with the medium sized aperture (#4).

   c. The effect of this "hot spot" on testing was determined by placing a man at each end of the testing bench (about ten feet apart) and presenting an equal number of settings of the ring to the left and to the right. The men were then reversed. There was a mixed random setting but only the settings to the right and to the left were evaluated. (There were 64 to the right and 64 to the left.) Each man made about four times as many errors when the opening in the ring was to the side opposite from which he was sitting. This phenomenon was much more pronounced with the smaller apertures. It was found that by using multiple apertures in the metal plate instead of a single aperture, the "hot spot" was practically eliminated. (See Figure 2) This was observed subjectively. It was also noted, that with the more diffuse brightness at the lower intensities, it was more difficult to make a correct response. The amount of "hot spot" that still remained was measured with the photometer, and it was found that there was still a 25% loss in brightness in going from the center to the field outside the Landolt ring. This remaining "hot spot" is due to the fact that the entire radium plaque is smaller than the testing field. The effect of the more diffuse brightness on actual testing was determined in the same manner as outlined in Paragraph c above. Now the examinees made only half as many errors when the opening in the ring was opposite to the side on which they were sitting, which is some improvement.

2. Type of tracing cloth not specified. - Ten different types of tracing cloth were tested. None of them eliminated the "hot spot," but they did differ in their transmission. By measuring the brightness of each sample (illuminated from behind by a standard bulb) with a Macbeth illuminometer, it was found that some samples were more than twice as bright as others.

[redacted]

3. Unavailability and expense of the Signal Corps switchboard. - A magnet switch connected to a counter could be placed directly on each response station. This would be cheaper and easier to record and would also eliminate the necessity of using an extra man as a recorder of scores. This technique is now in use on the Eastman Test.

4. Tendency for scores to pile up at end. - In the scattering of test scores on the Consolidated Test there was a tendency for piling up at the difficult end. (See Figure 5) Test means showed that there were 62.2% correct responses for the Consolidated as compared to 55.5% for the Eastman.

5. Personal variation in having an individual make random settings.- The Eastman has a nearly equal mixture of random settings due to its mechanical setting device. However, due to the slight "hot spot" present even with the multiple hole plates, and because this hot spot has a significant effect on the correct response made, the settings should be equally mixed. Two men were asked to make one hundred random settings on the Consolidated machine and each showed preferences, some settings being almost twice as popular as others (the least 9 and the most 17, the diagonal settings being somewhat more popular with both men).

6. Radium plaque is sensitive to light. As with all other radium plaque testers at present, the radium paint is light sensitive. If it can be obtained, a radium activated paint should be used which is not sensitive to light.

STATISTICAL APPENDIX

The statistical analysis is somewhat complicated by the occurrence of discrete observations (Eastman and Consolidated) with continuous observations (Hecht-Shlaer). Furthermore, high scores on the Eastman and Consolidated Tests are favorable whereas high scores on the Hecht-Shlaer Test are unfavorable. Fortunately these difficulties can be circumvented quite readily. First of all, the observations on the Eastman and Consolidated Tests are subtracted from 40 and 35 respectively, so that high scores are unfavorable on all three tests. Secondly, the Hecht-Shlaer Test produces slightly more favorable scores than the Eastman Test since according to Air Force standards the Hecht-Shlaer Test failed only 5 subjects, whereas the Eastman Test classified 20 as unsatisfactory. Likewise, if on the Consolidated Test we consider scores of 0-17 as unsatisfactory (the same relative scale as the Eastman Test), we see that 15 subjects are classified as unsatisfactory. Thus, without loss of information, in the analysis of variance, we can transform the Hecht-Shlaer scores so that the differences among the three means will be attributable only to the difference between the Eastman and Consolidated means. This transformation consists of multiplying the Hecht-Shlaer values by a constant so that the New Hecht-Shlaer mean will be equal to the average of the Eastman and Consolidated means. The resulting analysis of variance is not affected by such a transformation, except for the variation due to test means. (See Figure 6) The analysis discloses several interesting relationships.

1. The average individual score on the Eastman Test was 55.5% correct responses, and on the Consolidated 62.2% correct responses. The difference between these means is significant at the 5% level. It should be noted here that this test of significance is independent of the variation due to individuals and in-

[redacted]

dependent of learning effect. In other words, those effects were eliminated before the test of significance was performed.

2. The largest single source of variation was that due to order within tests, or learning effect. This effect was significant at the 1% level. The fact that this variation was so great emphasizes the necessity for eliminating learning effect before comparing test means.

3. Variations among individuals within groups and among the groups were also significant. This is by no means a new discovery, but it is important to note that this source of variation had to be removed before the test of the means could be performed.

The conclusions which one may draw from this analysis may be stated very simply. The Eastman and Consolidated Tests are different from one another; in particular a significantly higer proportion of correct response was observed on the Consolidated Test than on the Eastman Test. Since according to the present Air Force standards the Hecht-Shlaer would have failed only five and classified none as superior, it is probably safe to say that from this series it is unsatisfactory. There are a great many technical factors in standardization and personal factors in the performance of this test that could account for the poor showing of the Hecht-Shlaer in this study.

Of interest also are the correlations of the scores of particular groups of subjects classified on one test with their scores on the other tests. In order to compute these correlations, it was necessary to convert the scores on the Eastman and Consolidated Tests from number of correct identifications to number of incorrect identifications. This achieved the necessary parallelism on all three tests of direction of score and quality of performance. The correlations of interest are shown in Figure 7.

Since no one scored superior on the Hecht-Shlaer test and only 2 scored superior on the Eastman test, correlations were not computed for these groups. Each of the correlations among tests for all 60 subjects is significant at the .001 level. None of the other correlations in Figure 7 are statistically significant.

Figure 1

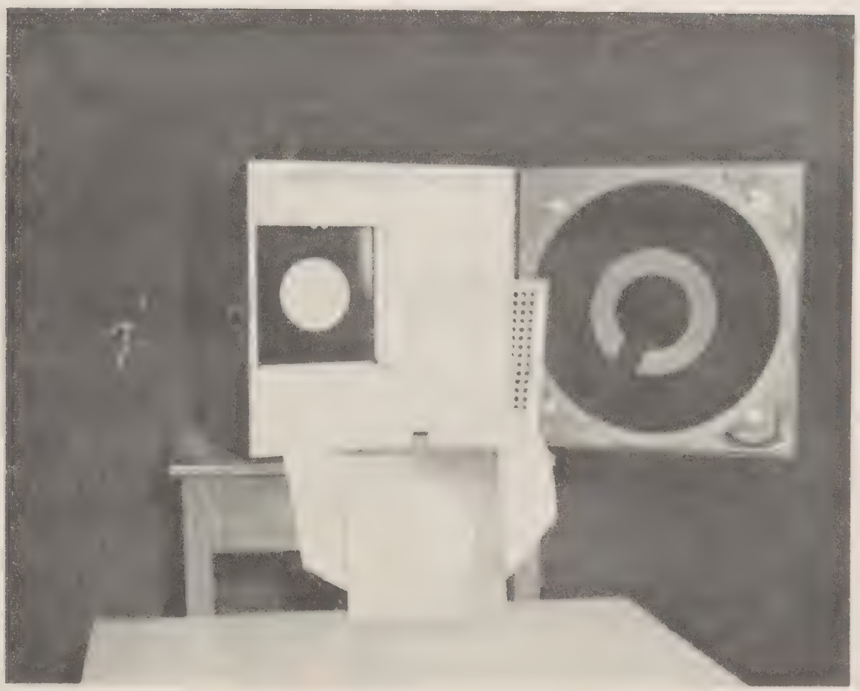


Figure 2

Scoring System Used in the Three Tests

Test	Failing	Passing	Superior
Eastman	0 - 19	20 - 35	36 - 40
Consolidated	0 - 17	18 - 31	32 - 35
Hecht-Shlaer	4.1 or more	3.0 - 4.0	2.9 or less

FIGURE 3

Number of Individuals by Performance on
Night Vision Tests

F = Failed P = Passed S = Superior

Performance On		Eastman F	Eastman P	Eastman S	Consolidated F	Consolidated P	Consolidated S	Hecht-Shlaer F	Hecht-Shlaer P	Hecht-Shlaer S
Eastman	F	20	-	-	13	7	0	5	15	0
	P	-	38	-	5	30	3	0	38	0
	S	-	-	2	0	1	1	0	2	0
Consolidated	F				18	-	-	2	16	0
	P				-	38	-	3	35	0
	S				-	-	4	0	4	0
	F							5	-	-
	P							-	55	-
	S							-	-	0

Figure 4

Scattering of Scores on the Eastman and the Consolidated Night Vision Tests

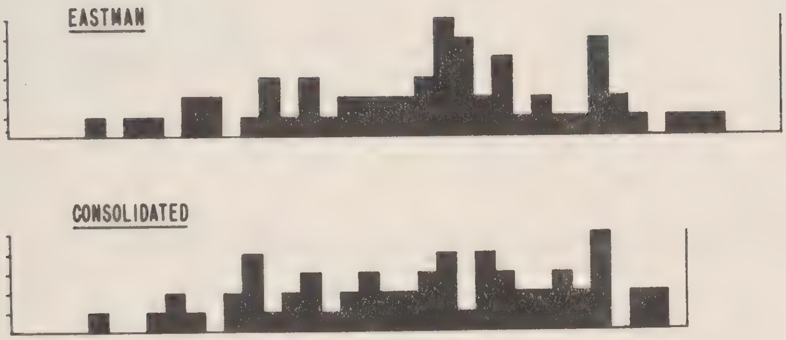


Figure 5

Analysis of Variance

Source of Variation	d.f.	s.s.	m.s.
Replications	5	.2318	.04636*
Individuals Within Replications	54	2.6322	.04874**
Tests	2	.1345	.06727*
Order Within Tests	2	.2336	.11680**
Error	116	1.7423	.01502
	179		

Test Means

Eastman	55.5%	correct responses
Consolidated	62.2%	" "
Hecht-Shlaer	3.60	Log micromicrolamberts

* P .05
** P .01

Figure 6

[redacted]

Correlations for Particular Groups of Subjects

Subject Group	Correlation With Eastman	Consolidated	Hecht-Shlaer
All 60: Eastman	-	.658*	.448*
Consolidated	.658*	-	.464*
Hecht-Shlaer	.448*	.464*	-
20 who failed Eastman	-	.273	- .077
18 who failed Consolidated	.015	-	.336
5 who failed Hecht-Shlaer	-.257	.453	-
4 who scored superior on Consolidated	-.689	-	- .233
* P .001			

FIGURE 7

DISCUSSION:

Dr. Uhlaner asked whether Lt. Ripple had obtained any test-retest reliabilities.

Lt. Ripple replied in the negative.

Dr. Rowland reported on the similarity between the Eastman night vision trainer and the consolidated night vision trainer. He stated that it was curious that Lt. Ripple's results indicated a 30% failure on each of these tests since the tests were designed to exclude only 5% of the population. He suggested that there must either be a difference in the machines or in humanity.

Dr. Andrews asked Lt. Ripple how many apertures were available for reducing illumination.

Lt. Ripple replied that there were seven apertures.

Dr. Andrews asked whether intercorrelations had been obtained between the various series of apertures. He expressed concern as to whether all 7 apertures were indeed needed for testing.

Dr. Sloan reported that it had been believed that all apertures were necessary in order to cover the entire populational variance in night vision capacity.

Dr. Andrews expressed concern over the large amount of error variance apparent in the results reported by Lt. Ripple, stating that the comparative conclusions drawn were at least partially invalidated by the error variance.

Captain Shilling asked whether the consolidated tester was the equipment used during the war by Major Rostenberg for which validity coefficients of 0.6 and 0.7 were reported.

Dr. Uhlaner replied in the affirmative.

Captain Shilling expressed surprise at the high validity coefficients in view of the apparently low reliability of the device.

Dr. Dimmick asked whether fixation points were used with the device.

Lt. Ripple replied in the negative.

Dr. Dimmick then commented that learning to scan may be a part of the error variance.

Lt. Ripple commented that perhaps the use of fixation points would not be desirable since they would tend to restrict the kinds of scanning adopted whereas a general training in scanning is more desirable.

Dr. Dimmick commented that in testing it would be highly desirable to know what retinal areas were being stimulated. Dr. Dimmick then inquired concerning the stability of the radium plaque in view of its high brightness.

Dr. Uhlaner reported that manufacturers' data indicated a half-life of 10 years. He reported further that in using the consolidated tester at AGO, the men are trained to scan and use peripheral vision before the test is administered.

Dr. Rowland reported that an experimental investigation during the war of the importance of a fixation light was conducted and that negligible difference was found. He reported, however, that the men tested preferred the fixation light.

Commander Farnsworth suggested that the use of a fixation light could be expected to have more effect upon some subjects than others, and questioned that Dr. Rowland's conclusion could be generalized.

Program of Ocular Fatigue Research
USAF School of Aviation Medicine

by

Saul B. Sells, Ph.D., R. B. Payne, Ph.D., Dept of Psychology
Paul H. Ripple, M.D., Dept of Ophthalmology

The previous research, just reported, used civilian patients, of both sexes, covering a wide age range, who were referred primarily for symptoms of asthenopia. These patients were all studied while wearing normal correction.

In considering the application of these findings to Air Force personnel it is necessary to validate the results: a) on an Air Force population having the following characteristics:

1) males

2) age range 18 to 55 years

3) refraction and muscle balance within limits of AF physical standards (A.R. 40-110);

b) working without correction; c) working under illuminations and with environmental conditions related to flying.

The proposed research will use a newly developed modification of the Howe-Berens ophthalmic ergograph. It is possible that the new ergograph, after standardization based on experimental data collection, may furnish a basis for a satisfactory clinical test of ocular fatigue. The planned studies will investigate loss of accommodative power (fatigue) in relation to illumination, to hypoxia (in altitude chamber) and in relation to night cockpit vision (under dark adaptation, with and without oxygen administration). It is believed that the results will contribute materially to our knowledge of the onset of and methods of postponing visual fatigue in flying.

1. Apparatus. The most recent ophthalmic ergograph, developed by Dr. Conrad Berens of New York City, was used recently by Berens and Sells in a research project using civilian patients. The results of that research indicated positive evidence of fatigue in both monocular and binocular tests following a period of thirty minutes of ergographic work. The new apparatus is based on this model, but includes a number of improvements, including (a) elimination of distractions in the visual field, (b) more adequate presentation and illumination of test object, (c) improved recording system, (d) elimination of motor noise, (e) greater flexibility with regard to range and quality of illumination of test object, and (f) provision for a wider range of experimental conditions.

Proposed Research Studies.

1. Standardization of ergograph test and post-test near-point decrement for Air Force men by age group.

2. A study of the effect of changes in illumination from 1 fc to 40 fc on near point decrement. In this and the following studies an experimental design will be followed which uses the same subjects as experimental and control groups. This type of control avoids many assumptions, frequently unwarranted, concerning the homogeneity of the sample populations. Statistical evaluation of results by the method of symmetry analysis will be done with the aid of the Department of Biometrics of USAF School of Aviation Medicine.

3. A study of the effect of altitude and oxygen deprivation on near point decrement. This study will be made in an altitude chamber at USAF School of Aviation Medicine, with the cooperation of the Department of Physiology.

4. A study of ergographic performance under conditions of cone threshold illumination. The visual field will be dark, the test object, a) black under red illumination, b) orange self-luminous under ultra-violet illumination (as in cockpit lighting in night flying). Subjects will be tested with and without dark adaptation, will in some cases inhale oxygen before the experiment, in some during the experiment, and in others will work without oxygen inhalation.

In each of the studies 2, 3 and 4, the standard work task developed in study 1 will be followed. It is planned that the ergograph task will be 30 minutes of continuous work. After each task the recovery curve will be studied. All subjects will be examined by the Staff of the Department of Ophthalmology before being admitted for experimental tests.

DISCUSSION:

Dr. Marquis asked what the relation is between "fatigue" as measured by the recession of the near point of accommodation and other physiological effects. He expressed his particular interest in the relation to the finding by Carmichael and Dearborn that there is no decrement in reading proficiency with "fatigue".

Dr. Sells reported that no subject was able to perform on the ergograph for the full 30-minute period. When the subjects stopped the task of their own volition, they apparently felt called upon to explain why they had stopped. Such reports were given as "my head hurts", "everything is blurred", etc. As for other interrelations, Dr. Sells reported that it had been shown that the decrement in accommodation amplitude caused by work on the ergograph was constantly related to recession of the near point of accommodation.

Dr. Marquis asked again whether it was not necessary to demonstrate the relation between this decrement in accommodation amplitude and visual performance. He asked whether, so long as an object is beyond the near point, near point ressession can be shown to represent any decrement in performance.

Dr. Sells agreed that there was as yet no evidence that decrement in accommodative amplitude was related to other visual performance attributes, but he suggested that the first step involves demonstrating a measureable and constant change in the visual system.

Dr. Blackwell commented upon the great interest among illuminating engineers in selection of an index of visual performance which is meanfully related to the "cost" of visual performance to the organism. Dr. Blackwell reported that apparently thresholds are not a valid index of the "cost" to the organism. He suggested that since accommodative amplitude is a measureable quantity, its validity as a measure of visual impairment might be established by the use of subjective and clinical reports.

Dr. Blackwell suggested that if such validity could be shown, then recession of the near point might become a very useful index in determining the effect of illumination or of other variables upon the visual process.

Dr. Berens expressed agreement concerning the importance of Dr. Blackwell's point about illuminating engineering.

Dr. Scobee mentioned that it has been shown that, because of accommodation-convergence linkage, most comfortable accommodation and greatest amplitude of accommodation occur when the eyes are depressed rather than level or elevated. He asked whether this might not suggest that the head position in the ergo-ophthalmograph be altered.

Dr. Sells stated that Dr. Scobee's suggestion sounded like a good one and that it could be tried.

Dr. Marquis suggested that it is the rate of movement or rate of contraction that is important in all physiological mechanisms. He suggested that perhaps the target in the ergograph should move a constant distance from each successive near point. Since the rate of movement of the target could be made constant, then the time between successive muscular contractions could be kept constant.

Dr. Berens thanked Dr. Marquis for this suggestion and expressed his agreement with the principle.

COLOR VISION MULTITESTER FOR AVIATION

by
Ingeborg Schmidt, M.D.

It is generally recognized that in fitness examinations a signal lantern test should be added to the color plate test. This lantern is used in the further testing of the individuals who fail the pseudo-isochromatic plate test to determine the degree of disability imposed by their defect and to determine whether they have sufficient color recognition ability to perform some specific task.

One large difficulty which must be overcome in developing such lantern tests is the tremendous variety in which the actual signals appear. Their brightness, hue and saturation vary with visibility, background and distance. There are individual signals and groups of signals, continuous signals and intermittent signals. A lantern test can only simulate some of these diversified conditions. This fact accounts for the diversity of present signal lanterns. Most of them in a haphazard and non-systematic way reproduce some of the signals of actual practice. Some of these lanterns allow for classification of examinees into three groups: passed, color defective safe, and color defective unsafe; while others classify into two groups: passed or failed.

The Color Threshold Tester of Louise Sloan Rowland, now used in the U.S. Air Force, forms an exception since it follows a carefully conceived principle: the signals, adapted to the color signals used in aviation, are shown as individual lights, beginning with an intensity which for persons with normal color vision is just above the threshold, and increasing continuously in brightness. Within these brightness series the color thresholds of the color defective are determined. Occasionally (as determined by Sloan Rowland) a color defective makes errors with brightnesses far above his threshold, whereas, he names colors near the threshold correctly. The result obtained with the CTT also may be affected at times by a sequence effect. For example, if a color defective is shown green first, and then white, he may call the green, white. If the colors are shown in reverse order, he may call the white, green, and give the correct response to green. Hence, this test cannot be termed a true color threshold test. Except for a few limiting cases which were difficult to judge, the CTT proved satisfactory in fitness examinations.

Since there is a desire to improve the fitness examinations to enable a more satisfactory separation of those fit from those unfit, it was planned to design a new lantern more accurately adapted to the conditions on an airfield than the present lantern tests. In 1941, I built a device in Germany which represented a sample of signaling practice. It deliberately contained signal compositions which color deficients find difficult to read. This test was passed by only a few color deficients who had been selected by a color plate test. In Germany I planned to improve this model and I am glad that I can continue my work in this country.

The Color Threshold Tester of Sloan Rowland demands maximum color efficiency, since for people even with a normal color vision it is difficult to discriminate colors near the threshold. The new lantern, using signals simulating those used

in aviation, is designed so any person with normal vision can pass it. It will be a "pass-or-fail" test. The conditions are as follows:

1. The signals are to be read at a certain minimum distance.

2. The brightness of the signals closely approximates the brightness of the most important signals in aviation practice.

3. No colors are shown but those which the pilot must be able to perceive, namely, red, green, white and yellow. Blue was omitted because it is not used except for taxiway markers which need be discriminated only at short distances.

4. As to frequency and composition, the colors are exhibited as they actually occur on the air field.

5. The signals are shown as they would appear under optimal weather conditions, since in case of poor visibility even a person with normal color vision may have difficulties in perception.

6. The signals are visible for 10 seconds, a period of time which seems ample for persons with normal color vision.

7. The brightness of the background must be similar to that of reality.

Description of Device and Examinations

The first model of the Color Vision Multitester was built by Mechanic Fleck in the workshop of the School of Aviation Medicine. Its main part is a dedecagonal drum which rotates clockwise about a light source. The drum rotates discontinuously so that the observer faces each side for 10 seconds and each corner for 5 seconds. After 24 such motions, the drum is stopped automatically. Eleven sides of the drum have three lights each, arranged vertically at a distance of 6.5 centimeters from each other. On the twelfth side a cross appears, indicating the end of the examination and serving for orientation on the records. In order to calculate the size of the signals it was necessary to determine the minimum distance at which signals on an air field must be perceived. The answers which pilots gave on this point varied considerably. We, however, had to maintain a certain minimum size for several reasons. For physical reasons the aperture should not be too small, in order to eliminate disturbing diffraction phenomena. The size of common testing rooms had to be considered also. Finally, a size of 0.6 mm diameter and a testing distance of 10 feet (3 m) were chosen. The lights then subtend an angle of about 40". This corresponds to the signals of a biscuit gun seen from a distance of 1 kilometer, a runway light at 600 m, or an obstruction light at 300 m.

The surface brightness of the signals was determined after measurements on air field signals and the light source for the lantern was selected accordingly. The result of these measurements is given in the tables shown in Figures 1 and 2. Some measurements were made in the open and some in the Laboratory with meters suiting the sensitivity of the eyes. It is not satisfactory to determine light source and filters separately, because reflections occur within the illuminating device and are difficult to estimate. Since one cannot consider all standard types of illumination and signals, some types were selected which a program of minimum requirements must contain. They are: (1) red obstruction lights with

three different light sources, (2) runway marker with the brightness calculated from the area of the light band produced by the zonal lens, and (3) biscuit gun representing a little searchlight. For the latter, the maximum brightness, the brightness of the core only was determined since the pilot must discriminate the color of this core light.

Horiz. Angle	Vertic. Angle	Specification AN-L-10	Samples Measured at Wright-Patterson AFB		Samples Measured at Randolph AFB		
			Obstacle Red in Candle Power				
			A-21 clear 325 Lumen		100 W 120 V	100 W 120 V	60 W 120 V
			Mold B_1	Mold B_2	clear.	frost.	frost.
20°	5°	13	20	28.5	18	27	13.5
	90°	1.5	14	19	23	23.5	10.5
			Runway Marker in Candlepower				
			A-21 clear 325 Lumen		T-13 clear 10 Watt 105 Volt		
87°	5°	500	1100		82		
87°	45°	20	10		15		
273°	5°	500	990		47		
273°	45°	20	10		11		

FIGURE 1

Object and Color	Color Temper. of Light (Source Average)	Horizon. Angle	Vertical Angle	Average Surface Brightness in Lambert I	II
Obstacle Red	2900°K	20°	5°	3.0	1.8
				2.6	1.4
Runway Marker					
Clear	2800°K	87°	5°	92 (approach)	
		87°	45°	13.5 "	
		273°	5°	53 (depart.)	
		273°	45°	10 "	
Green		87°	5°	13.5(approach)	
		87°	45°	2.9 "	
Amber		273°	5°	50 (depart.)	
		273°	45°	7 "	
Biscuit Gun					
Clear	3200°K		90°	700	1350
Green				230	325
Red				180	245

FIGURE 2

For comparison, measuring samples from Wright-Patterson Air Force Base and some specification standards are given. On the basis of all these measurements the light sources required for the lantern were determined. They are: a light source of the color temperature 2800° K and a brightness of 50 lamberts to represent the obstruction light and most of the runway lights (upper and lower row of the Multitester); and a light source of the color temperature 3200°K and more than 1000 lamberts to represent the biscuit gun and the brightest runway lights (center row of lantern). For the latter the color temperature must be reduced to 2800°K by Kodak filters. Thirty different bulbs were tested to find the most appropriate types. For the upper and lower row, several bulbs are suitable, but for the center row it is difficult to find the best adapted bulb. It would be possible to compensate a lack of brightness by enlarging the size of the light in accordance with the laws of differential thresholds. By using just the needed surface brightness the nearest approximation can be made.

The filters were selected as to color and saturation from samples of color filters employed on the air fields. The following types were chosen:

Red Corning #2412, 1.8 mm thickness
Green Corning #4445, 3.5 and 2 mm thickness
Amber Corning #3483, 2 mm thickness

White is produced by the light sources of corresponding color temperatures. Wratten Neutral Kodak filters were used to obtain the brightness required. Figure 3 indicates the total transmission of the air field filters and the Corning filters as measured with a filter photron element adapted to the sensitivity of the eye. Two light sources equal to the maximum color temperatures occuring in air field illumination served for illuminating: 2600°K as in the wind indicator lamp and 3100°K as in the biscuit gun. The total transmission of the red filter of the biscuit gun exceeds the transmission of the green filter. Whereas, the surface brightness of the red biscuit gun, as measured on the apparatus, is lower than the surface brightness of the green (See Figure 1). This probably is caused by reflections in the biscuit gun. In general the Corning filters simulate the air field filters. The exact specification of the filters being calibrated by the Bureau of Standards has not yet been received.

As mentioned above, the lantern has eleven rows of three signals each, making a total of thirty-three signals. From former experience this should be adequate for a color sense examination. For this lantern it will still have to be proved. It is important that several signals be displayed simultaneously, since single signals seldom occur in routine flying. No intentional traps for the color defectives were laid in the combination of the signals, they simply attempt to simulate the combinations possible on the air field. All odd rows in the middle contain a light equivalent to the biscuit gun, 2 red, 2 green, 2 white, the one in between 2 obstruction reds, the other between 2 white lights equaling the brightness of runway lights. The even rows contain representations of runway lights. White and red lights appear most, with green and yellow lights less often, which corresponds to actual frequency. Five subjects can be examined simultaneously if they are seated in a semicircle of 10 feet radius around the lantern (Figure 4). This fact accounts for the name "Multitester." Each examinee sees the 12 sides of the apparatus.

Another important issue is the brightness of the surrounding fields, which means the brightness to which the eye is adapted originally. In order to simulate the situation on an air field, a surrounding field of night-time brightness would

Colored Filters	Light Source Diameter 1.5 cm 3 lambert 2600°K % Transm.	33 lambert 3100°K % Transmission
RED		
Biscuit Gun		29
Obstacle Red	23.3	17.2
Wind Indicator	17.5	16.0
Corning No. 2412 1.8 mm	18.3	14.5
GREEN		
Biscuit Gun		24.9
Wind Indicator	14.5	21.3
Runway Marker	14.5	15.4
Corning No. 4445 3.5 mm	14.0	17.2
		20.5
AMBER		
Runway Marker	63.0	65.0
Corning No. 3484 2 mm	67.4	66.0

FIGURE 3

Fig. 4 Testing with the Color Vision Multitester for Aviation.

be required. On the other hand, we need a brightness sufficient for the examinee to write his own protocol. For this purpose an illumination equivalent to a full moon would be adequate. That means a surface brightness of about 0.1 asb (0.01 millilambert) and a color temperature of 4500°K. This can be accomplished by indirect illumination with a 30 Watt lumiline lamp, operating on a slightly lower voltage, plus a Corning daylight filter. For an illumination of 0.01 foot-candle the normal visual acuity is 0.3. Taking this into account, the protocol sheets were provided with thick black lines. After previous adaptation to bright light the eye can be adapted to a brightness level of 0.1 asb within 1 to 2 minutes. During this 1 to 2 minutes the time may be used to explain the testing procedure to the examinees, who have previously read the instructions on the protocol sheet. It is important to instruct the examinees that they must pay full attention once the Multitester is switched on; that after 5 seconds the first signal appears; that they must enter the colors they see in the respective columns of the sheet at once, since they disappear after 10 seconds; that after another 5 seconds a new signal will appear; that they must mark the cross at its respective place on the sheet, and that after the cross appears they must not stop but continue the test until all columns of the sheet are filled. Following this instruction the examiner switches on the apparatus and fades into the background. When the lantern stops automatically, he switches it off and gathers the sheets. The whole examination, exclusive of the evaluation, takes 5 minutes.

I am sorry that I cannot report experiences which I gathered with the Multitester for the reason that the final model is not yet completed. Some advantages over other lantern tests must be pointed out:

1. The examiner cannot influence the duration or sequence of the signals. Hence, with respect to the examiner, the apparatus is foolproof.

2. The examination may be given in a short period of time-- approximately 5 minutes.

3. The 5-second breaks eliminate sequence effects.

4. The examinees cannot complain of unjust classification, since they themselves fill out the sheets.

The Multitester will be compared to other testing methods, especially to the SAM CTT and the New London Navy Lantern. During these tests it will be determined whether the Multitester is suitable to determine color vision fitness.

DISCUSSION:

Mr. Breckenridge commented that in aviation lighting, the problem is to discriminate colored lights presented singly. He asked why Dr. Schmidt used concomitant presentation of lights.

Commander Farnsworth pointed out that the use of concomitant lights is a very delicate diagnostic tool, and has been shown to be decidedly superior to single presentations in the detection of color deficients. Commander Farnsworth reported that a color test had been built on the induced simultaneous contrast effect, indicating the high degree of sensitivity of the diagnostic value of simultaneous presentations.

Mr. Breckenridge asked Dr. Schmidt why the signal lights were of such high intensity rather than at threshold.

Dr. Schmidt replied that at high intensity, additional color errors are uncovered which do not appear near threshold intensity.

Dr. Grether asked whether the use of several lights simultaneously did not minimize the possibility that normals will make errors on the test.

Dr. Sloan reported that she had found in a study of the Canadian lantern that the average results with lights presented singly and in pairs were identical. However, she discovered that the colorblinds made more errors when one of the pair was white, but made fewer errors when red and green lights were paired. These two effects apparently canceled out in the average results. She reported the presence of both induced successive and simultaneous contrast and suggested that a carefully prescribed order of stimulus presentation was necessary.

ABSTRACTS

217. Development of Airport Control Tower Lighting
M. S. Gilbert
Civil Aeronautics Administration, Airport Development Division,
Technical Development
Technical Development Report No. 82, 7 pp.

"This report describes the development of a method for lighting airport control towers.

"Earlier experiments with "black," or ultra-violet, light were carried on at the Richmond, Virginia, control tower. Instruments and dials were painted with fluorescent paint which made them visible under the ultra-violet light, while allowing the eyes of the tower operators to remain dark-adapted. Also included in these experiments was a study of the use of red light for tower lighting. Operations were later transferred to the airport control tower at Weir Cook Airport, Indianapolis, Indiana, where experiments were continued with ultra-violet, red, and white light in various applications. The recommendations for the airport control tower lighting plan discussed in this report were made after a study of the results of these experiments.

"This plan involves the use of ultra-violet; also white and/or red light at the discretion of the tower personnel. The tower is divided into seven working areas and specific treatment is recommended for each area."

218. Determination of Field of Vision from Naval Combat Aircraft
H. G. Wagner
U. S. Navy, Bureau of Aeronautics, Aero Medical Equipment Laboratory,
Naval Air Experiment Station, Naval Air Material Center, Philadelphia
Report TED NAM AE-437002, 22 May 1947, 40 pp.

"The fields of vision from the cockpits of aircraft were measured in 18 types of Naval combat aircraft and reported.

"Photographs were taken of the field of vision in each plane to present some detail of the construction of the canopy and a measure of the field of vision in that cockpit. These photographs are appended to this report. A discussion of a quantitative field of vision and the qualitative comparison between bubble canopies and old styles ribbed and reinforced types is included in this report."

219. Some Factors Affecting the Size of the Eye-Pupil
K. H. Spring and W. S. Stiles
Great Britain, DSIR, National Physical Laboratory
Report No. PHOT. 3.1947, 7 pp.

A study was made to determine the relative effectiveness of axial and paraxial rays in establishing the size of the human pupil. The Stiles-Crawford effect would lead us to expect that paraxial rays would be less effective in causing pupillary constriction than axial rays of equal physical intensity. The authors

wondered whether there might not be an opposed factor, leading to increased effectiveness of paraxial rays, arising from the need for additional pupillary constriction to eliminate the rays striking the retina at an oblique angle.

Measurements were made on 12 subjects under brightness conditions selected to yield largest pupillary variations as a function of brightness. The results showed an average increase in pupillary diameter of about 0.3 mm. for a 4 mm. pupil arising from the use of completely paraxial rays. The effect was in the direction but of about one-half the magnitude to be expected from the Stiles-Crawford effect.

The authors concluded that the results indicated that the effect studied was not of practical significance in connection with design of optical instruments.

220. <u>Report on Survey of Lighting Preferences of a Group of Naval Aviators in the XAM-2 Cockpit Mockup.</u>
F. R. Brown
U. S. Navy, Bureau of Aeronautics, Aero Medical Equipment Laboratory, Naval Air Experiment Station, Naval Air Material Center, Philadelphia
Report TED No. NAM EL 600 Part 1, 20 October 1948, 24 pp.

"An opinion survey of a group of Naval Aviators has been made to determine preferences among several lighting schemes for the console and the instrument panel of the XAM-2 cockpit mockup. This mockup has a plastic plate, indirect lighting system for the consoles and a dummy panel indirect lighting system for the instrument panel. In addition, there is a supplementary floodlighting system. With particular reference to the question of the need for combining floodlighting with the indirect illumination on the consoles, more than half the preferences were for the combination of indirect lighting with low-level floodlighting rather than indirect lighting alone. The reason given for desiring additional floodlighting is the need for visibility of the control and indicating elements on the consoles. The combination is especially desired by the less experienced pilots and for those console areas where little provision has been made for indirectly illuminating the control and indicating elements by special techniques. For the instrument panel, the almost unanimous opinion was that indirect lighting alone was sufficient. Comment indicated that the floodlighting system should be carefully designed not only for supplementation of the indirect system but also so that it will be adequate to substitute for the indirect system should it fail."

221. <u>Some Experiments with the VF Aided Tracking Equipment.</u>
J. W. Gebhard
U.S. Navy, ONR, Special Devices Center, Psychological Laboratory of The Johns Hopkins University
Report 166-1-53, 15 September 1948, 30 pp. (R)

"Three experiments were performed to compare mechanically aided and manual tracking on the B-scope of the VF indicator.

"The first experiment measured bearing and range accuracy of continued tracking after the operator had centered the B-scope presentation on the target and de-

termined its course and speed.

"Results:

1. Bearing errors averaged 0.5° for all conditions. Since the simulated attack courses used had small bearing rates and large range rates, little adjustment was necessary to keep the target centered in bearing. The small bearing errors were judged to have no practical significance and therefore were not analyzed.
2. Range errors averaged 50 yards for the aided method and 42 yards for the manual method. The difference between methods is not statistically significant.
3. The difference between a four and an eight rpm rate of scan was statistically significant. The four rpm rate produced an average error of 63 yards and the eight rpm rate an error of 29 yards. The eight rpm rate was best for both tracking methods.

"The second experiment measured bearing and range accuracy of reestablished contact after simulated fades of two and four scans.

"Results:

1. Bearing errors were too small to warrant analysis.
2. The average error for the aided method was 33 yards, and for the manual method 64 yards. This difference is statistically significant.
3. The aided method was 'off target' by an average of 49 yards at the end of a fade. The manual method was in error by an average of 139 yards. This difference is statistically significant.
4. No statistically significant differences were found between a two-scan and a four-scan fade.

"The third experiment measured bearing and range accuracy during initial tracking adjustments on a target whose movement pattern was not yet established.

"Results:

1. Bearing errors were too small to warrant analysis.
2. The average error of the aided method was 65 yards and of the manual method 85 yards. This difference is not statistically significant.
3. The difference between four and eight rpm scanning rates is not significant.
4. Both aided and manual methods, once the target is centered on the B-scope, establish accurate tracking in three scans; i.e., the operator is tracking about as well as he ever will at the end of three scans."

222. Stray Light in Optical Systems.
U. S. Navy, Bureau of Ordnance (Pennsylvania State College, State Col., Pa.)
NavOrd Report 437, 22 March 1948, 52 pp.

"An objective method has been developed for measuring the stray light in optical systems. Stray light reduces the contrast of images and falsely appears to augment the light transmission of optical systems. The method utilizes a photoelectric apparatus to compare the contrast of an image formed by an optical system with the contrast of the object under examintion. This comparison, when expressed on a percentage basis, is referred to as 'the Contrast Rendition' of the optical system.

"The Contrast Rendition of telescopic, photographic, and microscopic systems has been studied under a variety of conditions. It has been found that the Contrast Rendition values ranged from 2 to 100 per cent for the systems studied.

"The Contrast Rendition of an optical system has been found to depend upon its optical and mechanical design, the use of reflection-reducing films, surface defects, the cleanliness of its optical surfaces, the use of lens shades, and the uniformity of brightness of the region surrounding the object under examination.

"The Contrast Rendition, for large targets and for a uniform surround, has been found to be independent of the brightness level at which the measurements are made, the contrast of the object, the field angle of the optical system under consideration, and the optical aberrations present for those optical systems studied.

"The importance of Contrast Rendition in telescopic systems has been evaluated using the methods and data of Hardy[1], Duntley[2], and Blackwell[3]. This evaluation was made by comparing the computed loss in range that would be caused by a percentage reduction in Contrast Rendition with the loss caused by an equal percentage reduction in light transmission and in magnification for telescopic systems. It was found, for all brightness levels, that the Contrast Rendition was generally more important than the other two variables.

"Because of the indicated strong dependence of the range at which targets are visible upon Contrast Rendition, ranges were computed for specific objects, instruments, and observation conditions, and compared with the results of an extensive visibility field test conducted from aboard ship. The computed and observed ranges were found to be in close agreement."

1. A. C. Hardy, J.O.S.A. 36, 283, (1946)
2. S. Q. Duntley, J.O.S.A. 36, 359 and 713 (A), (1946)
3. H. Richard Blackwell, J.O.S.A. 36, 624, (1946)

223. Studies in Visual Acuity.
U.S. Army, The Adjutant General's Office, Personnel Research Section
PRS Report No. 742, 1948, 161 pages, (0)

Final report of the AGO visual acuity study which has been discussed in detail in past Minutes and Proceedings of this Committee.

Opp-1,

NRL REPORT NO. N-3263

SURVEY OF THE BRIGHTNESS OF THE NIGHT SKY

Dr. Edward O. Hulburt

Dr. Edward O. Hulburt, Superintendent, Optics Division

Problem No. N26-03 April 1948

NAVAL RESEARCH LABORATORY
CAPTAIN H. A. SCHADE, USN, DIRECTOR
WASHINGTON, D.C.

DISTRIBUTION

BuShips Attn: Code 337-L	(2)
BuOrd Attn: Code AD-3	(2)
BuAer Attn: Code TD-4	(2)
ONR Attn: Code N-482	(2)
Dir., USNEL	(2)
ANESA	(1)
CO, SCEL Attn: Dir. of Eng.	(2)
OCSigO Attn: Ch. Eng. & Tech. Div., SIGTM-S	(1)
CG, AMC, Wright-Patterson Air Force Base Attn: Eng. Div., Electronics Subdiv., MCREEO-2	(1)
CO, AMC, Watson Labs., Red Bank Attn: WLGRD	(1)
RDB Attn: Library Attn: Navy Secretary	(2) (1)
Science and Technology Project Attn: Mr. J. H. Heald	(2)

TABLE OF CONTENTS

ABSTRACT

Values of the night sky brightness B are assembled from observations made in Brazil, Bikini, Maryland, New York State and Pic du Midi, France. From these data for clear air, no moon and no aurorae it appeared that throughout latitudes from 42° to -17° B on the average decreased from about 225 mμL at 15° above the horison to about 130 mμL at the zenith. Variations of B appear to be less than a factor of 2; they are neither completely observed nor completely understood, and at present may be said to be erratic. Some values of B for the Milky Way, the zodiacal light and the Magellanic Clouds are given. The effects of starlight and moonlight are discussed quantitatively.

A few data indicated that in the absense of aurorae B increased with latitude from north latitudes 44° to 80°. At Godhavn, Greenland, latitude 69°, for average aurorae the sky illumination on a horizontal plane was about 2 times its value for no aurorae and for a bright aurora was about 3 times.

SURVEY OF THE BRIGHTNESS OF THE NIGHT SKY

INTRODUCTION

In the following paragraphs are assembled various measurements made at various places of the brightness of the night sky. Some data for twilight and moonlight are also included. Experiments have shown that twilight has practically disappeared from the sky when the sun has descended about 18° below the horizon; for a depression of the sun below 18° the sky is in its full nighttime condition. The brightness is defined to be the brightness as viewed with the normal eye adapted to the illumination level under observation. It is convenient to use as units of brightness candles per square foot ($ca.ft.^{-2}$) and millimicrolamberts ($m\mu L$; 1 $ca.ft.^{-2} = 3.38 \times 10^{6}$ $m\mu L$.)

The following quantities are defined:

- B the brightness of a point in the sky in $ca.ft.^{-2}$ or $m\mu L$ as viewed with the eye adapted to the illumination level under observation,
- P the altitude in degrees above the horizon of a point in the sky,
- H the altitude in degrees above the horizon of the sun or the moon.

The polarization of the moonless night sky luminosity is small, less than a few percent, and will receive no further mention here.

The luminosity of the night sky in places remote from artificial illumination is due to several sources of light, all of which are at a considerable distance. The sources consist of atomic and molecular radiation from regions of the upper atmosphere probably in levels between 40 and 1000 km, sometimes termed the polar aurora and the nonpolar or permanent aurora; radiations and scattered sunlight from interplanetary space; and radiation and starlight from interstellar space. When one sees or measures the brightness of a place in the sky, he is seeing or measuring the sum of all the radiations which make up the sky luminosity.

Although many investigations have been made of the night sky most of them were done with photocells or with photography and were concerned with wavelength regions of the spectrum different from that of the eye. They therefore were of little application here and it has resulted that the present survey is based mainly on a few recent photometric investigations.

THE BRIGHTNESS OF THE MOONLESS NIGHT SKY

Several series of measurements of B of the moonless night sky as a function of P are given in Fig. 1. The four crosses in Fig. 1 are based on the data[1] obtained at the Whiteface Mountain Observatory, latitude 44° 30' north, longitude 73° 58' west, in clear weather from January 24 to April 23, 1942. The measurements were made by observers under the direction of Dr. Brian O'Brien of the University of Rochester. The crosses refer to the zenith and to points in the sky for P = 45° to the north, east, south and west. The value of each cross was an average of about 70 readings; individual readings varied not more than about 40 percent from the mean due probably both to instrument settings and to real variations in B. The measurements were made with a Rochester photometer[1], which was a visual photometer of field of view about 11° in diameter with a radium activated phosphor button as the comparison source. The photometer was calibrated against a non-selectively attenuated light source operating at 2360° Kelvin. In the observations bright stars and the Milky Way were avoided, and no strong aurorae were mentioned. The fact that the point to the north at P = 45° was a little brighter than the other points was probably due to slight aurorae.

The circles in Fig. 1 are average data[2] obtained on clear nights at a station near Bocaiuva, Brazil, latitude 17° 13' south, longitude 43° 41' west, and altitude 2200 feet. The photometer used was a radioactive button visual photometer copied from the Rochester instrument, the field of view being about 11° in diameter. Just as in the case of the Rochester photometer, the instrument was calibrated against a non-selectively attenuated light source operating at 2360° Kelvin. The data were averages of values taken between 9 and 12 P M in directions mostly north around to east during the period from middle of April to the middle of May, 1947. In the evening the zodiacal light was in the west and the Milky Way ran across the westerly and southerly quadrants; these luminous apparitions as well as the brighter stars were avoided in obtaining the values in Fig. 1. Two values for the brightest region of the Milky Way just above the Southern Cross are shown in Fig. 1 by the circles at 263 and 251 mµL.

The Magellanic Clouds were visible but not conspicuous in the southwest. In May in the evening the Large Cloud was at an altitude of about 15° and in that position added about 25 ± 15 mµL to the brightness of the neighboring sky.

The zodiacal light was plainly visible at the Bocaiuva station every clear night for about an hour after evening twilight and an hour before morning twilight; it could usually be seen up to about P = 45° but not to the zenith, and at P = 15° was about 25° to 30° wide. In Fig. 2 are given a series of measurements of B made before morning twilight on April 30,1947, of the central regions of the zodiacal light and of the sky alongside. The position of Venus is indicated in Fig. 2; in the last two sets of measurements in Fig. 2 the brightness below an altitude of 30° was due largely to the glow in the sky caused by the illumination of Venus and but little to that of the zodiacal light and the night sky.

A few measurements of B were made with the radio-active button visual photometer in June, 1946, at Bikini atoll, latitude 11° 35' north and 165° 30' east; they are plotted as squares in Fig. 1. Although the lower air was clear, the day horizontal visual range being almost always greater than 20 miles, continuous scattered clouds interferred with the night sky observations. The squares plotted in Fig. 1 were obtained from measurements on clear spaces of sky between the clouds; but for P below 45° the clouds, being in echelon, precluded any satisfactory views of the clear sky.

Measurements of B were made with the radio-active button visual photometer at a station in Maryland, a few feet above sea level and at latitude 38° 32' north, longitude 76° 10' west. The station was remote from the illumination of cities and towns. Two sets of the Maryland data are plotted in Fig. 1, the black dots being measurements made during two very clear nights in April, 1948, and the dots on crosses being measurements made on typical slightly hazy summer nights in July, 1943, when the day horizontal visual range was about 8 miles. It is seen that the effect of haze was to reduce the zenith value of B and to flatten out the maximum in the B, P curve, which is at about P = 15° for a clear atmosphere. The effects of haze are in accord with theoretical expectation. The Maryland data were averages of observations made to the southeast, south and southwest.

The fact, apparent in Fig. 1, that the maximum in the Maryland B, P curve for a clear atmosphere (shown by the black dots) was below the maximum of the B, P curve for Bocaiuva (shown by the circles), was believed to be due mainly to the slightly greater amount of haze in the Maryland air than in the Bocaiuva air. Unquestionably the night sky toward the horizon was darker at the Maryland station than at Bocaiuva, and as far as memory served the stars in the Maryland sky, although the nights seemed very clear, did not seem as brilliant as those in the Bocaiuva sky.

The dotted curves of Fig. 1 are the values of B as a function of P <u>relative</u> to the value of B at zenith observed[3] in August, 1943, at the Pic du Midi Observatory, latitude 42° 56' north longitude 0° 40' west, and altitude 12600 feet. The zenith value was arbitrarily plotted at 100 in Fig. 1. The measurements were made with a photomultiplier photometer of field of view 6° in diameter. The instrument was not calibrated in photometric units, and gave only relative brightness values. A yellow green filter limited the spectral sensitivity mainly to the region from about 5300 to 5800 A with a maximum at about 5600 A; there was a small amount of sensitivity from 6000 to 6400A.

The two lower dotted curves of Fig. 1 were observed in an ESE direction from the Pic du Midi, the three upper curves in a north direction. The two lower curves were regarded as normal; the three upper curves, and other similar curves not drawn in Fig. 1, were considered

to indicate the auroral enhancement of the yellow green luminosity of the north sky near the horizon. The air was clear during these observations.

The literature concerning the variability of the night sky luminosity is extensive, and a detailed summary will not be attempted here. Many variations in the night sky spectrum have been observed, diurnal, seasonal and irregular; some have been related to terrestrial magnetic activity. The variations differed in different portions of the spectrum, and few of them have either been fully observed or fully explained. The amplitudes of the intensity changes were small, being less than a factor of two, except when polar aurorae were present. It has not been completely determined what portions of the changes in the sky brightness were due to the observer being exposed to different portions of planetary or galactic space and what portions were due to changes in the molecular and atomic radiations from the upper atmosphere. Most of the observations have been carried out in latitudes above 35° where polar aurorae are often present, and it would be of interest to make similar observations in low latitudes where polar aurorae are rare.

The effect of stars on night sky brightness observations deserves discussion. From star counts[4] it is known that the total light of all the stars equals that of 1092 stars of visual magnitude $M = 1.0$, and that 4/5 of the light comes from stars of less brightness than about $M = 6$ which are not resolved individually by the unaided eye from the surrounding night sky luminosity. If it is assumed that the stars are distributed uniformly over the sky, the equivalent 1092 first magnitude stars produce an illumination at the earth which would be the same as that produced by a uniformly bright sky of $B = 32.6$ mμL. The average sky brightness equivalent to all the stars less bright than $M = 6$ is $4/5 \times 32.6 = 26$ mμL. This is somewhat less than the observed values of B which, from Fig. 1, are usually greater than 120 mμL. However, the stars are not uniformly distributed over the sky but are concentrated in the galactic region (the Milky Way), and therefore the unresolved stars contribute considerably to B in some regions of the sky and little in other regions.

When using a visual photometer to measure B the observer can usually avoid regions of very bright stars, but it is rare that he can find regions where there are no stars visually resolved. Thus he usually observes B with one or more stars visible in the field of the photometer and makes the instrument setting by putting attention on the general field brightness, thereby consciously discounting to some extent the effect of the visually resolved stars; but the more nearly the stars approach $M = 6$, the less of such discounting that is done. With a photoelectric photometer, however, the effect of bright stars may be appreciable, because the instrument records the total illumination which it receives without discrimination as to the source of the illumination. For example, the illumination from a single star of $M = 0$, 1 and 2 is equivalent to that from a circular area of sky 5° in diameter of brightness $B = 129$, 51 and 20 mμL, respectively. These values are comparable with the observed values of Fig. 1, which range between 100 and 300 mμL. Therefore if a photoelectric photometer of 5° diameter

field of view is used, data obtained with it should be corrected, or interpreted, for visually resolved stars when compared with data obtained with a visual photometer. However, as yet there are no photoelectric measurements of night sky brightness in visual photometric units.

AVERAGE BRIGHTNESS OF THE MOONLESS NIGHT SKY FOR LATITUDES BELOW 45°

The foregoing observations support the general conclusion that over a large portion of the earth the variations of the moonless night sky brightness B with time, geographical location and position in the sky fall within rather small limits probably less than a factor of two, as long as the air is clear. In Table 1 are listed values of B which are

Table 1. Average values of B for clear air for latitudes below 45°.

P	B
90° zenith	130 mμL
80°	130
70°	135
60°	135
50°	140
40°	150
30°	175
20°	210
15°	225
10°	225
5°	200
2°	180

weighed averages of the data of Fig. 1, and apply to latitude -17° to + 45° for regions of the moonless night sky outside of the Milky Way and the zodiacal light, when no polar aurorae were noticeably present and when there were no luminous occurrences as planets, comets, meteors, lightning, volcanoes, fire-flies, etc. The values of Table 1 are considered to be the same for all directions around the compass.

THE BRIGHTNESS OF THE NIGHT SKY IN HIGH LATITUDES

Measurements of the sky brightness in north latitudes from 44° to 80° reported by Fessenkoff[5] are listed in Table 2. His values of B, given in the third column of Table 2, were in relative units and were averages of

Table 2. Sky Brightness near Polaris

Station	Latitude	B relative	B reduced to mμL
Simeiz	44.3° north	0.30	150
Petrovka	46.8	0.312	156
Kuchino	55.8	0.57	285
Bay Tikhaya	80.3	1.20	600

observations made from October 1940 to April 1941. They refer to a region of the sky near Polaris at about local midnight when the sun was more than 20° below the horizon and when there was no moon and no appreciable aurorae. A visual photometer was used with a radio-active luminous field, the field of view being about 5°; similar photometers were at each station. If one assumes that B for the sky near Polaris at Simeiz was about 150 mμL, then 0.30 of Fessenkoff's brightness units equals 150 mμL. On this assumption the last column of Table 2 was calculated.

Night sky brightness data when aurorae were present and absent were obtained by Garrigue[6] at Godhavn, Greenland, latitude 69° 20' north, during the winter and spring of 1938-1939. A visual photometer of about 15° field of view was used with red, green and blue filters. In Table 3 are given certain of his values of B in his relative units for the green filter Wratten No. 61N. With the same photometer with the green filter Garrigue observed 173 and 207 for the sky at P = 90° and 10°, respectively, at the Pic du Midi observatory, latitude 42° 56' north. If one assumes that B for the zenith sky at Pic du Midi was 130 mμL, then 173 of Garrigue's brightness units equal 130 mμL. The last column of Table 3 was calculated from this assumption.

Table 3. Brightness data at Godhavn.

Condition	B relative		B reduced to mμL
Darkest night, no aurorae	Sky at P=10°	280	210
	Sky at P=90°	180	135
	Snow	230	173
Average night, no aurorae	Sky at P=10°	450	338
	Sky at P=90°	317	237
	Snow	301	226
Average of 35 aurorae	Sky	---	---
	Snow	564	424
Brightness aurora Dec. 12, 1938	SW sky at P=30°	4000 to 7000	3000 to 5300
	Snow	740	557

This Laboratory plans to carry out a program of night sky brightness measurements with visual photometers with cooperating observers in Alaska, Canada and the United States.

THE BRIGHTNESS OF THE SKY DURING TWILIGHT

In Table 4 are given values of B during twilight in clear cloudless weather observed at Bocaiuva[2] for various altitudes H of the sun. B was observed for the zenith sky for H from 0° to -20°, and for points in the sky at an altitude P = 15°, and hence not far from the horizon, in directions east, north and west for H from -12° to -20°. A Macbeth illuminometer of field of view 5° in diameter, with calibrated blue filter to match the sky color, was used for the zenith B values for H from 0° to -12°, and the Rochester type of photometer, of field 11° in diameter, for the values of B from H = -12° to -20°. During the measurements bright stars were avoided. B was not measured to the south for P = 15°; from symmetry one would expect the southerly values to be the same as those of the north of column 4, Table 4. It is seen that after the sun had reached 18° or 19° below the horizon the effects of solar twilight had disappeared and B had descended to its full night values in all the parts of the sky observed. The high value of 360 mμL for P = 15° to the west for H below -18° was due to the combined effect of the zodiacal light and the Milky Way at this point. As shown by the gaps in Table 4 for P = 15° no measurements were made of B for H from 0° to -12°; because, during

this part of twilight certain regions of the sky are visibly colored, and the special photometric arrangements had not been prepared which were necessary for measuring the brightness of colored areas.

Some values of B at sunset, H = 0, from the observations of Kimball at Washington[7] and of Dorno at Davos[8], Switzerland, are in the first two rows of Table 4. Values of the brightness B_h of a white, mat, horizontal surface exposed to the twilight sky, calculated from the measurements of Kimball[8], are given in column 7, Table 4.

THE BRIGHTNESS OF THE SKY IN MOONLIGHT

A number of measurements of the brightness of the moonlit sky were made by the University of Rochester observers[1], and it is of interest to compare them with the values calculated from the data for sunlight. Since the spectrum and polarization of moonlight are approximately the same as of sunlight, and since the moon appears about the same size as the sun, one may calculate B and the polarized components of B for moonlight by multiplying the solar values by f/465000 for similar positions of the sun and moon in the sky and for the same atmosphere in the two cases. The number 465000 is the ratio of full moonlight to sunlight[10] and f is a fraction which accounts for the phase of the moon. To B obtained in this way must be added the light of the night sky.

An example is given in Table 5, in which is entered the calculated brightness for the full moon at an altitude H = 40°, for points in the sky at altitudes P at 15° intervals from P = 15° to 90°, for 5 directions Z to the bearing of the moon at 45° intervals from Z = 0° to 180°. The upper number of each entry in Table 5 is the daylight value of B for the same H, P and Z observed at Bocaiuva, Brazil[11], multiplied by 1/465000 and reduced to mμL. The lower number of each entry is the night sky value of Table 1, assumed to be the same in any direction for P constant. The brightness of the moonlit sky is the sum of the two entries.

Values of B observed at Whiteface Mountain[1] for a clear sky on January 29, 1942, for P = 45° for the moon at H = 45° and phase 0.888 were from about 1000 to 3200 mμL. An average value given in Fig. 13A[1] for the full moon was 3200 mμL. These values are in rough accord with Table 5. The comparison is made with some reserve, because it is not known whether the clarity of the atmosphere was the same at Bocaiuva and Whiteface Mountain.

From Table 5 it is seen that due to the light of the full moon the night sky brightness is about 10 times that of the moonless night sky. Since the moon is above the horizon during more than 1/3 of the time that the sun is below 18° below the horizon, and is of phase greater than 0.1 about 9/10 of this time, it is apparent that moonlight is an important source of the brightness of the night sky during about 1/3 of the nocturnal hours. This is for a clear atmosphere; the relative importance of moonlight increases with an increase of haze in the air.

Table 4. Value of B and B_h during evening twilight

Altitude of sun	Zenith $P = 90^\circ$	$P = 15^\circ$				White Horizontal Surface	Observing Station
		East	North	West	South		
H	B	B	B	B	B	B_h	
0°	5 $ca.ft^{-2}$	30	15	24	15 $ca.ft^{-2}$	10.5 $ca.ft^{-2}$	Washington
0°	13	51	39	137	39	--	Davos
0°	23	--	--	--	--	--	Bocaiuva
-2°	7.6	--	--	--	--	4.78	Bocaiuva
-4°	1.0	--	--	--	--	0.99	and
-6°	0.11	--	--	--	--	0.127	Washington
-8°	0.011	--	--	--	--	0.0127	"
-10°	5080 mμL	--	--	--	--	8480 mμL	"
-11°	2230	--	--	--	--	--	Bocaiuva
-12°	1020	4280	6800	12000	--	--	"
-13°	520	1730	3300	5700	--	--	"
-14°	300	930	1400	2400	--	--	"
-15°	220	500	780	1160	--	--	"
-16°	180	360	500	630	--	--	"
-17°	160	295	350	400	--	--	"
-18°	150	260	290	360*	--	--	"
-19°	150	250	250	360*	--	--	"
-20°	150	250	250	360*	--	--	"

*Combined effect of night sky, the zodiacal light and the Milky Way.

Table 5. Calculated values of B in mμL for full moon at altitude 40°

Z	P = 15°	P = 30°	P = 45°	P = 60°	P = 75°	P = 90°
0°	5300 225	6830 175	— 145	2060 135	1370 132	1100 130
45°	4120 225	2580 175	1980 145	1560 135	1330 132	1100 130
90°	2660 225	1760 175	1370 145	1200 135	1160 132	1100 130
135°	2920 225	1510 175	1090 145	982 135	982 132	1100 130
180°	3440 225	1720 175	1120 145	966 135	988 132	1100 130

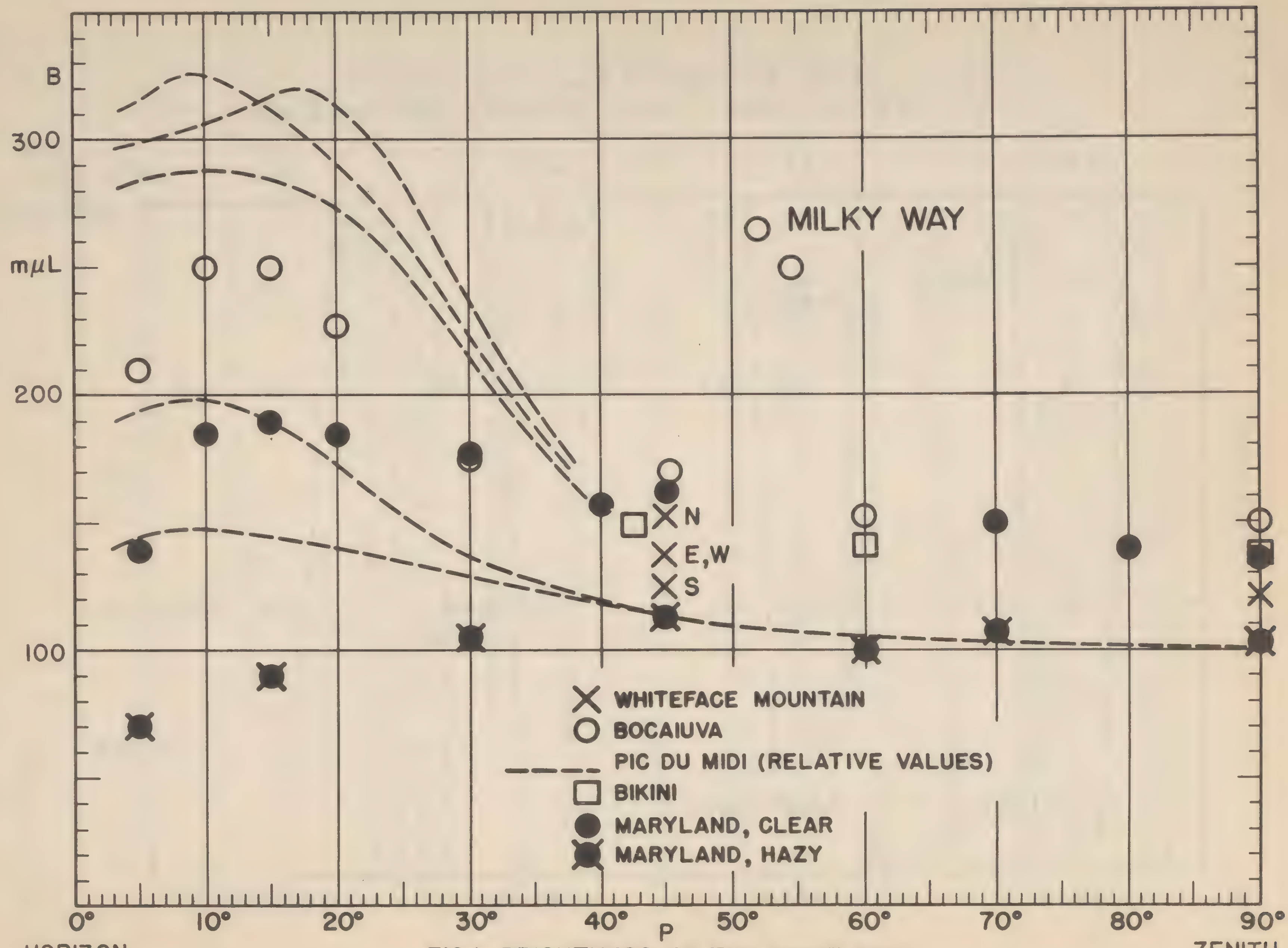


FIG.1 BRIGHTNESS OF THE NIGHT SKY

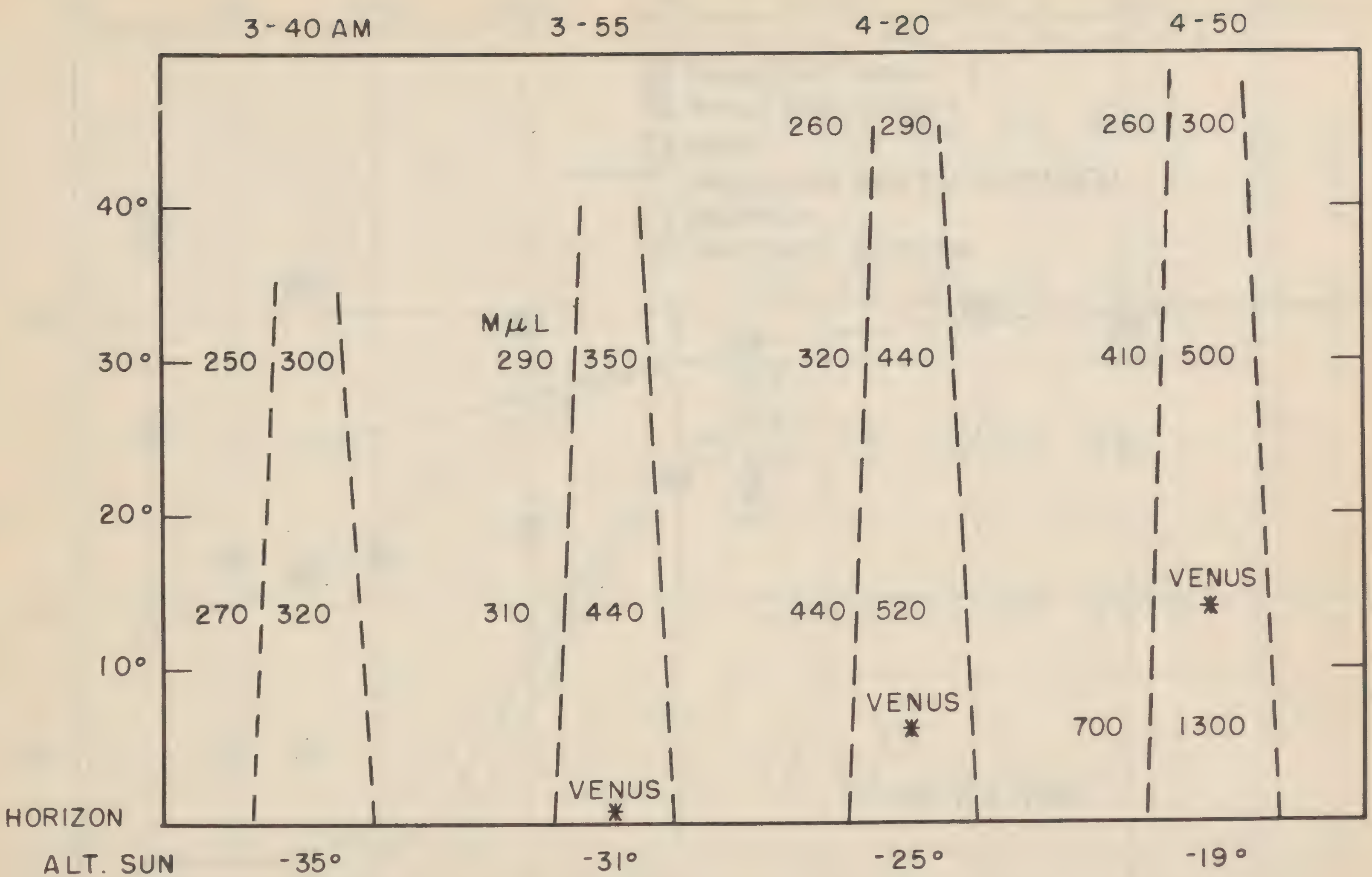


FIG. 2 MORNING ZODIACAL LIGHT, APRIL 30, 1947
BRAZIL, LAT. -17° 12.8', LONG. 43° 41.3'

REFERENCES

1. OSRD Report "A series of measurements of the brightness of the night sky", and the supplement thereto, Institute of Optics University of Rochester, 1943.

2. R. A. Richardson and E. O. Hulburt, "Brightness of the night sky near Bocaiuva, Brazil". A paper to be published in a technical report of the National Geographic Society.

3. P. Abadie, A. Vassy and E. Vassy, Ann. de Geophysique, 1, 189-224 (1944-45).

4. H. N. Russell, R. S. Dugan and J. Q. Stewart, "Astronomy", Vol. 2, page 625 (1926). Ginn and Company.

5. B. Fessenkoff, Comptes Rendues (Doklady) Acad. Sci. URSS, 32, 320-322 (1941).

6. M. H. Garrigue, C. R. Acad. Sci. (Paris), 209, 769-771 (1939).

7. H. H. Kimball, Trans. Illum. Eng. Soc., 16, 255-283 (1921).

8. C. Dorno, Veroff. d. Preuss. Met. Inst., Abh. 6 (1919).

9. H. H. Kimball, Mon. Weather Rev., 44, 614-620 (1916).

10. H. N. Russell, R. S. Dugan and J. Q. Stewart, "Astronomy", Vol. 1, page 173 (1926). Ginn and Company.

11. R. A. Richardson and E. O. Hulburt, "Brightness and polarization of the daylight sky near Bocaiuva". A paper to be published in a technical report of the National Geographic Society. See also Naval Research Laboratory Report No. N-3257, February, 1948.

PRNC-6104-6-14-48-300

App. 2,

NRL REPORT NO. N-3257

THE BRIGHTNESS AND POLARIZATION OF THE DAYLIGHT SKY

Dr. Edward O. Hulburt

Dr. Edward O. Hulburt, Superintendent, Optics Division

Problem No. 37N26-03 February 1948

DEPARTMENT OF THE NAVY ★ OFFICE OF NAVAL RESEARCH ★

NAVAL RESEARCH LABORATORY

CAPTAIN H. A. SCHADE, USN, DIRECTOR

WASHINGTON, D.C.

DISTRIBUTION

BuShips	
Attn: Code 337-L	2
BuOrd	
Attn: Code AD-3	2
BuAer	
Attn: Code TD-4	2
ONR	
Attn: Code N-482	2
Dir., USNEL	2
ANESA	1
CO, SCEL	
Attn: Dir. of Eng.	2
OCSigO	
Attn: Ch. Eng. & Tech. Div., SIGTM-S	1
CG, AMC, Wright-Patterson Air Force Base	
Attn: Eng. Div., Electronics Subdiv., MCREEO-2	1
CO, AMC, Watson Labs., Red Bank	
Attn: WLGRD	1
RDB	
Attn: Library	2
Attn: Navy Secretary	1
Science and Technology Project	
Attn: Mr. J. H. Heald	2

ABSTRACT

Tables of values of the brightness B and polarization p of the daylight sky, when free of clouds, at Washington, D.C., Davos, Switzerland, Bocaiuva, Brazil and Maryland are assembled and compared. The data refer to points in the sky from the horizon to the zenith on bearings from the sun around the compass and to altitudes of the sun from 0° to about 60°. A table and relations are given from which B and p may be estimated for various altitudes above sea level. The effects on B and p of the reflectivity of the surface of the earth are discussed; B and p of the night sky in moonlight are mentioned.

THE BRIGHTNESS AND POLARIZATION OF THE DAYLIGHT SKY AT SEVERAL LOCALITIES FOR SEVERAL ALTITUDES ABOVE SEA LEVEL

In the following pages are assembled observations of the brightness and polarization of the daylight sky at several localities and at several altitudes above sea level. The data were taken from four series of measurements carried out at Washington, Davos, Bocaiuva and Maryland, which are the most extensive available at the present time. The survey is limited to sky values for the sun above the horizon and hence does not deal with twilight. An exception to this is that moonlight is considered, because moonlight is approximately the same as sunlight of diminished intensity.

The following quantities are defined:

- H altitude of the sun,
- P altitude of the point in the sky under observations,
- Z the bearing of the point in the sky relative to the sun,
- B candles per square foot, brightness of the point in the sky, as viewed with the light adapted eye,
- p the polarization factor, defined as the ratio of the brightness of the sky when the polarizer is set for minimum transmission to the setting (at right angles) for maximum transmission. p varies from 0 for complete plane polarization to 1 for no plane polarization.

The Washington values are given in Figs. 1, 2 and 3; they were obtained by Kimball[1] in the period from April 5 to July 14, 1921, near Washington, D. C., latitude 38° 56' north, longitude 77° 2' west, and altitude about 70 feet above sea level. The values of B for average clear skies are in Figs. 1 and 2, and for cloudy skies in Fig. 3. Only B was measured, no observations of p were made. The larger numbers at the ends of the curves of Figs. 1, 2, and 3 are the values of B in millilamberts, and may be reduced to candles per square foot by dividing by 3.38. The smaller numbers at the other ends of curves are the brightnesses in terms of the brightness of the zenith sky.

The Davos data of Table 1 were averages over a year for clear skies observed by Dorno[2] at Davos, Switzerland, latitude 46° 48' north, longitude 9° 49' east, and altitude 5250 feet, during the years 1911 to 1918. In Fig. 4 is shown Dorno's Tables 12a, 12b and 12c, which were used in preparing Table 1. B of Table 1 was calculated by the relation B $ca.ft.^{-2} = i_g \times 26.7$, where i_g is the number in Dorno's Table 12a. p of Table 1 was calculated from Dorno's Tables 12b and 12c by the relation $p = i_1/i$ if i_1 is less than i or p i/i_1 if i is less than i_1. The gaps in Table 1 shown by stars referred to points of the sky close to the sun where no measurements were made.

The Bocaiuva data[3] of Table 2 were averages of observations made during the period from April 15 to May 14, 1947, at Bocaiuva, Brazil, latitude 17° 13' south, longitude 43° 41' west, altitude 2200 feet. Over a thousand readings were made when the sky was clear and the values of Table 2 were read from smooth curves drawn through the plotted observations. The stars in Table 2 were for places in the sky close to the sun where no measurements were made.

The Maryland data[4] of Table 3 were derived from observations made from an airplane flying at 10000 feet over Maryland, latitude 40° north and longitude 75° west, during the period from September 1941 to March 1942. Table 3 is a theoretical table which agreed closely with the observations as long as the sky was clear. Because of the limitations of the flight programs it was not practicable to make a complete set of measurements at all points in the sky at all altitudes of the sun. Therefore the theory was developed, and when it was found to agree with the observations, it was used for extrapolation and interpolation with some confidence to prepare Table 3. Since Table 3 was calculated from theory it contained no gaps for points in the sky close to the sun.

In comparing the data of the four stations one should remember that the amount of haze in the air above an observer has by far the most important effect on the brightness and polarization of his sky. For example, the effect of haze is much greater than effects of diminished air density due to increase of altitude up to 10000 feet. In Table 4 the data of the four stations for three points in the sky are assembled for comparison. From this table and other similar ones not presented here, it was concluded:

(a) That the sky brightness B for Davos, Bocaiuva and Maryland (10000 feet) decreased in the order named in accord with the idea that the haze decreased in the order named. B for Washington was relatively erratic being sometimes above, between and below B for the other three stations. Kimball[1] noted "that Dorno's measurements (at Davos) show a brighter horizon and a brighter sky opposite the sun than is indicated by the Washington measurements, probably on account of the light reflected by the snow covered Alps."

(b) That the polarization factor p for Maryland (10000), Bocaiuva and Davos was roughly proportional to 100, 110 and 130, respectively, and hence the amount of polarization decreased with increasing haze.

The brightening of the sky toward the sun is conspicuous in the data of the three stations. Davos, Bocaiuva and Washington. This is termed the "aureole" and is caused by the forward scattering of light by particles of diameters greater than the wavelength of light. Hence the aureole is a sure indication of haze in the air. For normally clear skies the brightness of the aureole was observed to be weaker at Maryland (10000 feet) than at Bocaiuva, and weaker at Bocaiuva than at Washington. The values of Table 3 do not reflect the aureole, for they were calculated from a theory which assumed a Rayleigh type of scattering and not a forward scattering.

Since haze is a very important factor in controlling the brightness of the sky, in any program of sky measurements one should determine the haze as completely as possible. For example, one should measure the distribution, scattering and attenuation of the haze at all altitudes. This of course is a large order and has never been done. In the case of the Maryland and Bocaiuva investigations, as a partial measure the attenuation b per vertical atmosphere was determined by measuring the solar illumination for several altitudes of the sun. b is defined by the statement that sunlight viewed with the light adapted eye is reduced to e^{-b} of its value in passing vertically through the atmosphere, e being the Naperian base. When the air was normally clear it was found that b was about 0.5 at Bocaiuva (2200 feet) and 0.136 at Maryland (10000 feet). For pure air molecules b is 0.1008 as calculated from the Rayleigh scattering formula with polarization defect[4].

The effect on B and p of the reflectivity r of the surface is shown in Table 5 which lists for two points in the sky the theoretical values at 10000 feet calculated[4] for r increasing from 0 to 1. It is seen from Table 5 that B and p increase with r. Thus, other things being equal, one would expect a brighter and less polarized sky over a snow field, or above thick clouds, where r may be nearly 1, than over the sea where r is usually less than 0.06. Although there is no reason to question the correctness of the foregoing relations between B, p, and r, the relations have not yet been observed by direct experiment, because direct experiment is difficult.

The values of B and p of the zenith sky at various altitudes above the surface were measured in a number of airplane flights to 10000 feet and in one flight to 18800 feet[4]. After the plane had risen above the haze level usually at several thousand feet and was in an approximately homogeneous atmosphere, the measurements showed that B was approximately proportional to the pressure and that p decreased very slowly with altitude, at the rate of about 1/10 per 10000 feet increase in altitude. These changes of B and p with pressure were found to be in close agreement with theory[4]. During the stratosphere flight of 1935 of the balloon "Explorer II" B was measured for $Z = 90°$ and $P = 38°$ up to 72000 feet[5]. When plotted

against the pressure Y, the B, Y curve was a straight line. No correction was made for the changing altitude of the sun which rose from $H = 0^\circ$ to $H = 30^\circ$ during the ascent of the balloon. However, it turned out from Table 3 that the B, H curve at 10000 feet was approximately a straight line for H from 0° to 40° for $Z = 90^\circ$ and $P = 38^\circ$. This indicated, but did not constitute rigorous proof, that the B, Y curve, if corrected for the changing H, would be a straight line. Therefore, the evidence available at present indicates that B is proportional to the pressure for $P \geq 38^\circ$. For P near the horizon one would expect that B would not be proportional to the pressure, but more probably would be constant with decreasing pressure.

In Table 6, column 2, are given the values of the pressure for the U. S. Standard Atmosphere . In column 3 are given the pressure ratios referred to the pressure at 10000 feet. From these, together with the values of B of Table 3 one may estimate B at altitudes above 10000 feet by assuming that B is proportional to the pressure. Above 10000 feet one may assume that p of Table 3 decreases exponentially by about 1/10 for each 10000 feet increase of altitude. The assumptions are probably not true for P near the horizon. For altitudes below 10000 feet the assumptions certainly fail when the region of prevalent haze is entered.

There are no extended series of measurements of the brightness and polarization of the sky in moonlight; however, the effect of the moon may be calculated from the daylight data. Since the spectrum and polarization of moonlight are approximately the same as of sunlight, and since the moon appears about the same size as the sun, one may calculate B and the polarized components of B for moonlight by multiplying the solar values by f/465000 for similar positions of the sun and moon in the sky and for the same atmosphere in the two cases. The number 465000 is the ratio of full moonlight to sunlight[7] and f is a fraction which accounts for the phase of the moon. To B obtained in this way must be added the light of the night sky which is practically unpolarized. The contributions to the sky brightness due to the full moon and to the night sky luminosity are in many cases of the same order of magnitude. This may be seen as follows: B of the moonless night sky in clear weather with no polar aurorae, is within the range 3×10^{-5} to 2×10^{-4} ca. ft^{-2}. From Tables 1 to 3 B for the day sky ranges from about 10 to 1500 ca.ft.$^{-2}$; for the full moon the range is found by dividing these numbers by 465000, which gives approximately 2×10^{-5} and 3×10^{-3} ca.ft.$^{-2}$.

The foregoing data may be regarded as an adequate survey of the brightness and polarization of the daylight sky for a number of cases. There are several cases for which further observations might be desirable; for example, values of B and p over the sky for altitudes of the sun below 5° and above 60°; values of B and p around the horizon, i.e., for P less than 10°, for all altitudes of the sun; and values of B and p for the observer at altitudes above 10000 feet. Finally, a case may be mentioned which is rather extensive, namely, a repetition of all the measurements for atmospheres in all stages of haze from very clear to thick fog.

REFERENCES

1. H. H. Kimball, "Sky brightness and daylight illumination measurement" Trans. Ill. Eng. Soc. 16, 255-283 (1921).

2. C. Dorno, Veroff. d. Preuss. Met. Inst., Abh. 6 (1919).

3. R. A. Richardson and E. O. Hulburt, "Brightness and polarization of the daylight sky at Bocaiuva." A paper to be published in a Technical Report of the National Geographic Society.

4. R. Tousey and E. O. Hulburt, "Brightness and polarization of the daylight sky at various altitudes above sea level." Jour. Opt. Soc. Am. 37, 78-92 (1947).

5. R. P. Teele, Nat. Geog. Soc. "U. S. Army Air Corps Stratosphere Flight of 1935 in balloon "Explorer 11", pages 133-138.

6. W. G. Brombacher, National Advisory Committee for Aeronautics, Report No. 538 (1935). "Altitude-pressure tables based on the U. S. standard atmosphere."

7. H. N. Russel, R. S. Dugan and J. Q. Stewart, "Astronomy," Vol. 1, page 173 (1926), Ginn and Company.

TABLE 1. Brightness B $ca.ft^{-2}$ and polarization p at Davos, altitude 5250 feet.

Zenith sky, P = 90°

H	B	p
0	13	0.14
10	66	.30
20	117	.40
30	160	.53
40	209	.70
50	283	.86
60	403	.97

Z = 0°

	P = 60°		P = 45°		P = 30°		P = 20°	
H	B	p	B	p	B	p	B	p
0°	20	0.49	33	0.77	75	0.68	137	0.49
10°	121	.66	206	.93	450	.85	718	.68
20°	217	.78	392	.94	720	.83	*	*
30°	293	.95	582	.96	*	*	1410	.80
40°	490	.99	*	*	1140	.83	1290	.92
50°	850	.89	*	*	960	.96	1042	.96
60°	*	*	943	.84	849	.96	849	.79

Z = 45°

	P = 60°		P = 45°		P = 30°		P = 20°	
H	B	p	B	p	B	p	B	p
0°	19	0.33	25	0.50	48	0.57	65	*
10°	100	.52	138	.55	208	.62	306	0.60
20°	167	.66	224	.63	360	.61	432	.65
30°	248	.75	353	.64	433	.62	578	.67
40°	337	.79	409	.82	485	.71	757	.61
50°	425	.84	477	.88	546	.86	676	.77
60°	572	.85	568	.83	607	.77	716	.70

TABLE 1. Davos (continued)

$Z = 90^\circ$

	P = 60°		P = 45°		P = 30°		P = 20°	
H	B	p	B	p	B	p	B	p
0°	17	0.15	20	0.15	32	0.16	39	*
10°	90	.24	115	.21	133	.25	1910	0.24
20°	140	.32	156	.32	199	.32	302	.29
30°	186	.38	205	.32	287	.27	379	.26
40°	221	.47	240	.40	349	.32	425	.28
50°	262	.66	262	.60	334	.51	393	.48
60°	328	.72	324	.62	356	.51	493	.47

$Z = 135^\circ$

	P = 60°		P = 45°		P = 30°		P = 20°	
H	B	p	B	p	B	p	B	p
0°	15	0.27	21	0.38	34	0.46	42	*
10°	79	.25	93	.32	148	.39	199	0.46
20°	118	.28	147	.34	211	.44	332	.48
30°	144	.28	162	.25	229	.24	345	.31
40°	173	.34	196	.27	291	.29	402	.34
50°	192	.51	200	.34	251	.33	371	.42
60°	234	.61	234	.41	267	.29	397	.38

$Z = 180^\circ$

	P = 60°		P = 45°		P = 30°		P = 20°	
H	B	p	B	p	B	p	B	p
0°	16	0.29	22	0.78	38	0.96	51	1.00
10°	79	.35	105	.51	149	.76	241	.91
20°	118	.31	160	.43	237	.65	357	.88
30°	144	.29	179	.38	*	*	396	.62
40°	152	.38	194	.31	280	.41	381	.44
50°	163	.49	189	.34	266	.34	330	.50
60°	210	.58	202	.39	250	.32	291	.42

TABLE 2 Brightness B ca. ft^{-2} and polarization p at Bocaiuva, altitude 2200 feet.

Zenith sky, P = 90°

H	B	p
5°	53	0.10
10°	75	.15
20°	102	.24
30°	127	.40
40°	151	.54
50°	179	.67
60°	206	.79

Z = 0°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	67	0.26	87	0.48	128	0.71	220	1.00	*	*
10°	93	.34	133	.57	208	.81	374	1.00	*	*
20°	133	.51	189	.72	302	.93	1340	1.00	2100	1.00
30°	162	.62	230	.91	520	1.00	*	*	1010	1.00
40°	188	.77	285	.95	*	*	940	1.00	729	1.00
50°	226	.88	502	1.00	*	*	439	.93	543	.86
60°	*	*	*	*	*	*	391	.84	404	.75

Z = 45°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	65	0.20	87	0.30	112	0.38	165	0.50	298	0.51
10°	90	.27	113	.35	150	.47	224	.52	407	.51
20°	123	.38	153	.50	211	.60	306	.60	518	.60
30°	153	.53	190	.61	248	.68	349	.66	566	.62
40°	183	.65	221	.70	273	.75	357	.68	566	.58
50°	213	.79	248	.80	282	.78	350	.68	521	.52
60°	242	.91	272	.87	279	.81	324	.63	417	.40

TABLE 2 Bocaiuva (continued).

Z = 90°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	56	0.10	77	0.07	91	0.06	123	0.11	197	0.11
10°	75	.12	94	.12	112	.11	145	.14	256	.11
20°	106	.25	119	.23	143	.19	181	.18	311	.13
30°	133	.39	142	.34	168	.27	220	.21	347	.16
40°	159	.53	167	.43	189	.36	242	.26	367	.16
50°	181	.64	185	.54	200	.42	250	.32	382	.18
60°	198	.74	198	.64	202	.44	244	.34	382	.21

Z = 135°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	59	0.11	74	0.19	100	0.28	145	0.49	235	0.49
10°	80	.14	86	.16	111	.25	167	.38	317	.45
20°	103	.20	106	.14	133	.21	192	.25	375	.39
30°	119	.27	120	.19	146	.19	207	.22	399	.34
40°	135	.36	135	.27	150	.19	209	.20	401	.30
50°	157	.50	150	.35	154	.19	210	.19	383	.24
60°	176	.66	164	.62	164	.26	210	.19	361	.17

Z = 180°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	63	0.19	73	0.30	105	0.57	158	0.89	277	0.95
10°	79	.15	89	.24	122	.45	194	.72	380	.93
20°	98	.15	109	.20	145	.34	237	.62	470	.80
30°	118	.23	120	.19	155	.24	251	.53	489	.72
40°	136	.35	133	.23	154	.18	237	.39	473	.60
50°	151	.47	141	.28	152	.17	210	.22	415	.37
60°	167	.58	149	.34	148	.16	191	.11	344	.15

TABLE 3 Brightness B ca. ft^{-2} and polarization p at Maryland, altitude 10000 feet.

Zenith sky, P = 90°

H	B	p
5°	44	0.12
10°	56	.14
20°	77	.23
30°	93	.35
40°	109	.50
50°	123	.65
60°	137	.79
70°	146	.90
80°	152	.98
90°	157	1.00

Z = 0°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	54	0.14	76	0.37	114	0.62	172	0.80	320	0.97
10°	67	.25	90	.47	130	.70	196	.88	359	.99
20°	91	.42	114	.65	156	.85	235	.97	424	.98
30°	112	.57	131	.79	177	.94	259	1.00	450	.94
40°	130	.73	150	.90	191	.98	270	.97	449	.85
50°	144	.85	165	.97	200	.98	270	.89	431	.73
60°	154	.94	175	1.00	201	.94	261	.79	409	.59
70°	159	.98	180	.97	197	.85	248	.67	385	.48
80°	160	.99	173	.89	189	.73	229	.53	355	.37
90°	158	.94	161	.79	175	.59	209	.39	327	.24

Z = 45°

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	48	0.13	76	0.23	94	0.38	142	0.53	250	0.55
10°	62	.19	83	.31	111	.44	160	.57	282	.57
20°	87	.34	106	.47	140	.56	188	.62	236	.59
30°	106	.48	127	.61	161	.67	205	.65	367	.58
40°	124	.63	144	.73	177	.75	223	.66	380	.54
50°	138	.76	159	.78	187	.80	232	.65	380	.50
60°	149	.88	165	.89	190	.79	236	.62	371	.44
70°	152	.95	169	.90	188	.76	232	.58	358	.37
80°	158	.97	167	.87	182	.68	222	.50	352	.30
90°	158	.94	161	.79	175	.59	209	.39	327	.24

TABLE 3 Maryland (continued)

$Z = 90^\circ$

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	54	0.08	64	0.08	87	0.07	103	0.07	194	0.07
10°	63	.11	72	.10	97	.10	114	.09	211	.08
20°	78	.20	87	.19	110	.16	135	.13	240	.11
30°	94	.33	102	.30	120	.24	154	.19	266	.15
40°	112	.47	117	.43	133	.33	170	.24	285	.17
50°	127	.62	131	.55	146	.42	183	.28	302	.20
60°	138	.75	143	.64	158	.49	194	.33	313	.22
70°	147	.85	150	.73	164	.55	200	.36	319	.23
80°	153	.92	157	.77	170	.58	205	.38	323	.24
90°	158	.94	161	.79	175	.59	209	.39	327	.24

$Z = 135^\circ$

	P = 75°		P = 60°		P = 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	51	0.06	62	0.08	80	0.25	112	0.35	254	0.53
10°	59	.07	69	.09	90	.22	124	.32	268	.48
20°	72	.14	80	.11	103	.16	144	.25	291	.38
30°	87	.23	91	.15	111	.14	156	.20	306	.32
40°	100	.37	102	.22	120	.16	163	.17	309	.25
50°	114	.50	114	.32	129	.22	168	.16	306	.21
60°	129	.63	126	.44	137	.29	172	.18	304	.18
70°	140	.75	139	.55	160	.38	180	.23	306	.18
80°	150	.85	150	.67	170	.49	194	.30	312	.20
90°	158	.94	161	.79	175	.59	209	.39	327	.24

$Z = 180^\circ$

	P = 75°		P = 60°		P= 45°		P = 30°		P = 15°	
H	B	p	B	p	B	p	B	p	B	p
5°	53	0.07	71	0.18	104	0.39	160	0.68	303	0.90
10°	60	.08	76	.17	110	.35	168	.61	338	.83
20°	73	.12	83	.15	116	.28	177	.47	357	.70
30°	85	.20	90	.14	116	.20	175	.35	365	.57
40°	99	.33	102	.18	120	.16	170	.25	360	.45
50°	112	.46	110	.27	124	.17	169	.18	340	.33
60°	126	.59	121	.38	131	.23	170	.17	317	.23
70°	137	.71	132	.52	142	.35	175	.20	301	.16
80°	145	.82	147	.65	167	.46	188	.28	304	.16
90°	158	.94	161	.79	175	.59	209	.39	327	.24

TABLE 4. Comparison of the sky data of four stations

Zenith, P = 90°

	Brightness B ca.ft^{-2}				Polarization p		
H	Washington	Davos	Bocaiuva	Maryland	Davos	Bocaiuva	Maryla
0°	5	13	23	--	0.14	—	—
5°	—	—	53	44	--	0.10	0.12
10°	--	66	75	56	.30	.15	.14
20°	113	117	102	77	.40	.24	.23
30°	—	160	127	93	.53	.40	.35
40°	230	209	151	109	.70	.54	.65
50°	—	283	179	123	.86	.67	.79
60°	494	403	206	137	.97	.79	.79

Z = 90°, P = 30°

	Brightness B ca.ft^{-2}				Polarization p		
H	Washington	Davos	Bocaiuva	Maryland	Davos	Bocaiuva	Maryla
0°	10	32	—	—	0.16	—	—
5°	—	--	123	103	--	0.11	0.07
10°	--	133	145	114	.25	.14	.09
20°	168	199	181	135	.32	.18	.13
30°	—	287	220	154	.27	.21	.19
40°	290	349	242	170	.32	.26	.24
50°	---	334	250	183	.51	.32	.28
60°	355	356	244	194	.51	.34	.33

Z = 180°, P = 30°

H	Washington	Davos	Bocaiuva	Maryland	Davos	Bocaiuva	Maryla
0°	17	38	—	—	0.96	—	—
5°	—	---	158	160	--	0.89	0.68
10°	—	149	194	168	.76	.72	.61
20°	124	237	237	177	.65	.62	.47
30°	---	---	251	175	---	.53	.35
40°	154	280	237	170	.41	.39	.25
50°	—	266	210	169	.34	.22	.18
60°	242	250	191	170	.32	.11	.17

TABLE 5. Maryland sky values at 10000 feet as a function of r.

H = 30°, P = 90°			H = 30°, P = 60°, Z = 180°	
r	B	p	B	p
0	83	0.31	79	0.08
0.2	93	.35	90	.14
0.4	101	.39	99	.20
0.6	111	.42	110	.24
0.8	121	.45	121	.29
1.0	129	.47	130	.34

TABLE 6. U.S. Standard Atmosphere

Altitude feet	Pressure mm Hg.	Pressure ratio	Altitude feet	Pressure mm Hg.	Pressure ratio
0	760.0	1.45	40000	140.7	0.269
2000	706.6	1.35	42000	127.9	.246
4000	656.3	1.25	44000	116.3	.223
6000	609.0	1.16	46000	105.7	.202
8000	564.4	1.08	48000	96.05	.184
10000	522.6	1.000	50000	87.30	.167
12000	483.3	.924	52000	79.34	.152
14000	446.4	.854	54000	72.12	.138
16000	411.8	.788	56000	65.55	.125
18000	379.4	.725	58000	59.58	.114
20000	349.1	.668	60000	54.15	.104
22000	320.8	.614	62000	49.22	.0942
24000	294.4	.564	64000	44.73	.0855
26000	269.8	.517	66000	40.66	.077[illegible]
28000	246.9	.473	68000	36.95	.0[illegible]
30000	225.6	.432	70000	33.59	.064[illegible]
32000	205.8	.394	72000	30.53	.0583
34000	187.4	.354	74000	27.75	.0531
36000	170.4	.326	76000	25.22	.0483
38000	154.9	.296	78000	22.92	.043[illegible]
			80000	20.83	.0398

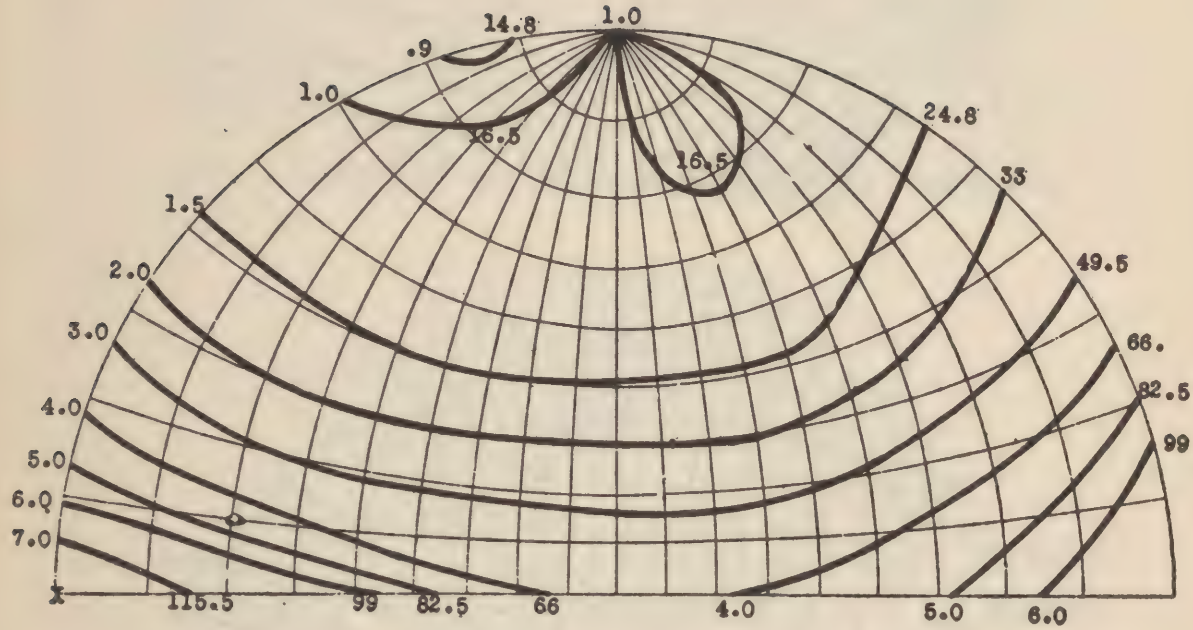


Fig. 1. Average brightness of a clear sky at Washington in millilamberts. X is Sun's position.

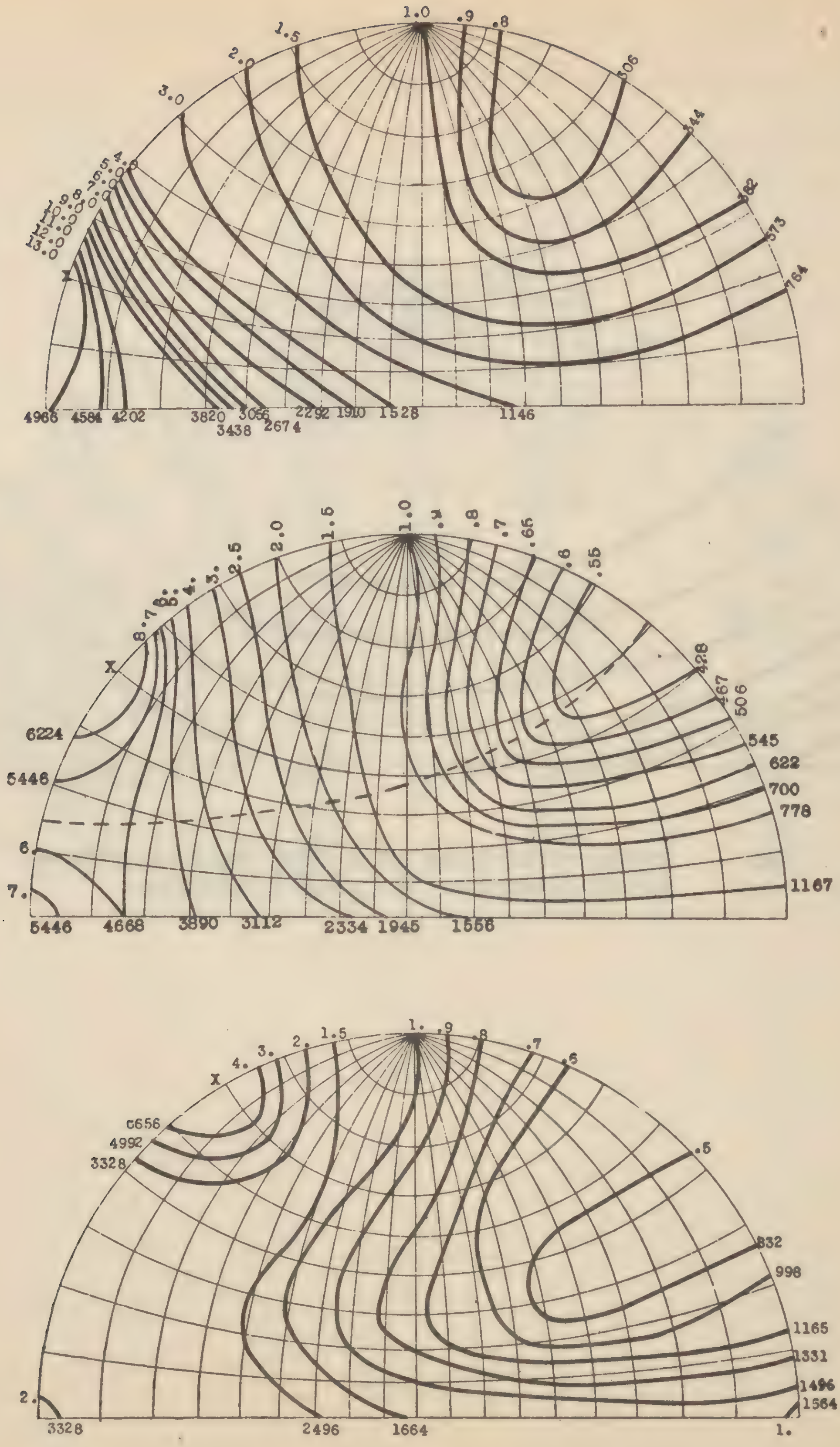


Fig. 2. Average brightness of a clear sky at Washington in millilamberts. X is Sun's position.

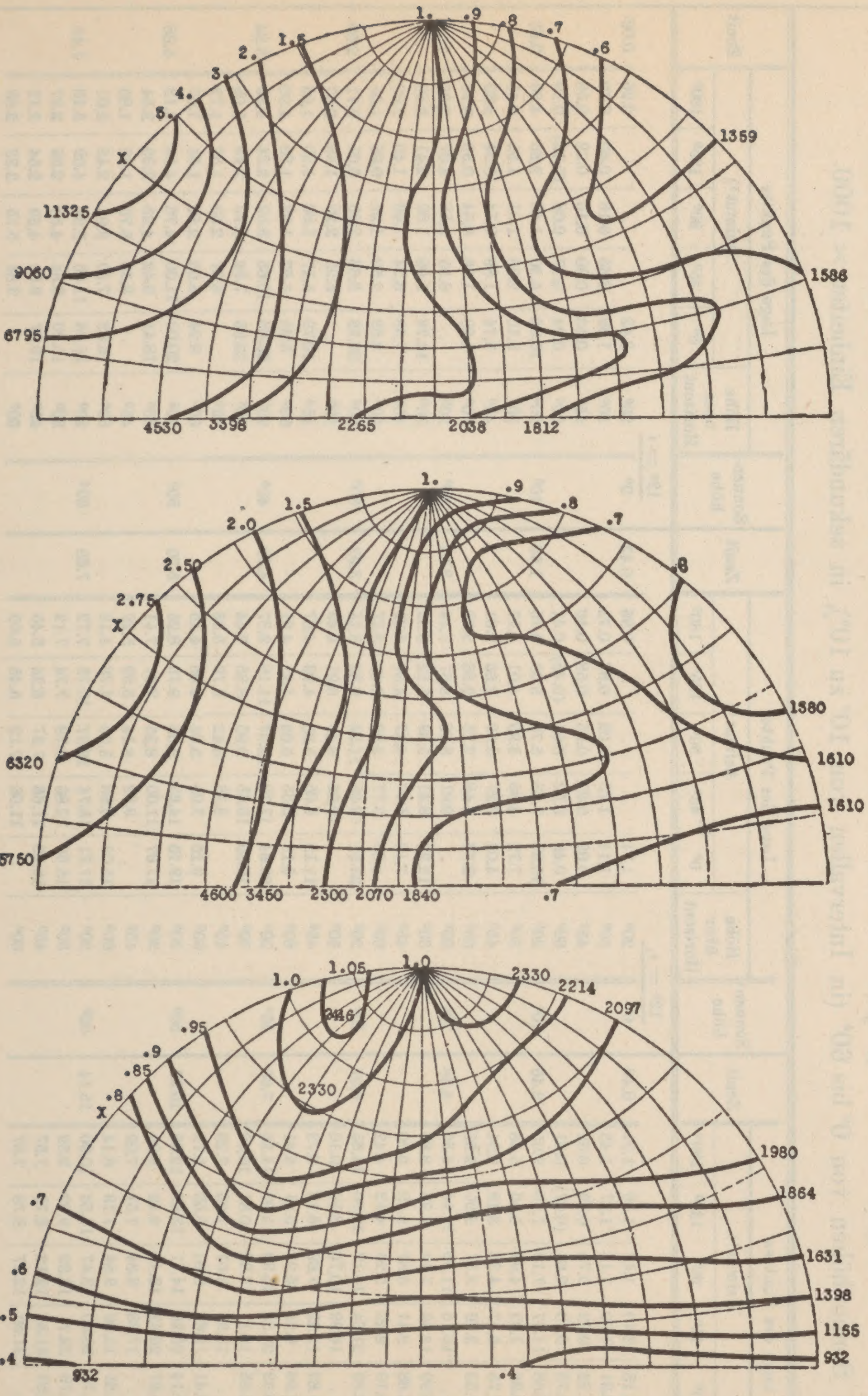


Fig. 3. Average brightness in millilamberts of the sky at Washington covered with thin clouds, partly covered with clouds, and covered with dense clouds. X is Sun's position.

Tab. 12[a—c].

Jahresmittel der Helligkeitsverteilung $i_g i_1 i$ am Himmel ausserhalb der bis zu 10° um die Sonne laufenden Zone bei Sonnenhöhen von 0° bis 60° (in Intervallen von 10° zu 10°), in sekundären Einheiten × 1000.

$12^a = i_g$

Sonnenhöhe	Lage des Punktes: Höhe über Horizont	Azimut[1]) 0°	45°	90°	135°	180°	Zenit
0°	20°	5.13	2.40	1.46	1.59	1.91	0.48
	30°	2.81	1.80	1.18	1.27	1.43	
	45°	1.22	0.92	0.75	0.79	0.82	
	60°	0.73	0.70	0.63	(0.57)	0.61	
10°	20°	26.88	11.47	7.18	7.45	9.05	2.46
	30°	16.83	7.82	4.99	5.56	5.58	
	45°	7.75	5.17	4.33	3.49	3.94	
	60°	4.53	3.76	3.37	2.95	2.95	
20°	20°	.	16.16	11.30	12.44	13.36	4.38
	30°	26.99	13.49	7.49	7.93	8.89	
	45°	14.68	8.41	5.87	5.48	6.00	
	60°	8.19	6.26	5.26	4.42	4.42	
30°	20°	52.89	21.64	14.19	12.80	14.85	6.01
	30°	.	16.29	10.76	8.59	10.16	
	45°	21.82	13.22	7.69	6.13	6.73	
	60°	11.96	9.32	6.97	5.41	5.41	
40°	20°	49.33	28.34	15.90	15.03	14.25	7.83
	30°	43.85	18.17	13.08	10.81	10.49	
	45°	.	15.35	9.01	7.36	7.28	
	60°	18.41	12.61	8.30	6.50	5.72	
50°	20°	39.14	25.28	14.71	13.87	12.38	10.58
	30°	35.97	20.42	12.48	9.42	9.95	
	45°	.	17.88	9.84	7.51	7.09	
	60°	31.85	15.98	9.84	7.19	6.14	
60°	20°	31.79	26.80	18.47	14.84	10.90	15.14
	30°	31.79	22.71	13.32	9.99	9.39	
	45°	35.53	21.34	12.12	8.78	7.57	
	60°	.	21.50	12.27	8.78	7.87	

$12^b = i_1$

Sonnenhöhe	Lage des Punktes: Höhe über Horizont	Azimut[1]) 0°	45°	90°	135°	180°	Zenit
0°	20°	1.71	.	.	.	0.96	0.42
	30°	1.14	1.15	1.02	0.87	0.73	
	45°	0.69	0.62	0.65	0.58	0.46	
	60°	0.49	0.52	0.55	(0.45)	0.41	
10°	20°	10.87	7.18	5.78	5.09	4.75	1.93
	30°	7.72	4.85	3.99	4.01	3.17	
	45°	4.03	3.27	3.59	2.66	2.61	
	60°	2.73	2.48	2.73	2.36	2.19	
20°	20°	.	9.81	8.76	8.37	7.14	3.12
	30°	12.22	8.41	5.69	5.52	5.39	
	45°	7.10	5.17	4.47	4.07	4.21	
	60°	4.60	3.77	3.99	3.46	3.37	
30°	20°	23.51	12.98	11.24	9.80	9.14	3.92
	30°	.	10.03	8.47	6.91	6.49	
	45°	11.12	8.05	5.83	4.93	4.87	
	60°	6.13	5.35	5.05	4.21	4.21	
40°	20°	23.64	17.70	12.37	11.19	9.87	4.60
	30°	19.89	10.65	9.95	8.35	7.44	
	45°		8.38	6.42	5.79	5.56	
	60°	9.16	7.05	5.64	4.86	4.15	
50°	20°	19.15	14.39	9.95	9.73	8.25	5.70
	30°	17.67	11.00	8.25	7.07	7.41	
	45°	.	9.52	6.14	5.59	5.29	
	60°	15.03	8.68	5.93	4.76	4.13	
60°	20°	17.71	15.74	12.57	10.75	7.72	7.68
	30°	15.59	12.86	8.78	7.74	7.12	
	45°	16.20	11.66	7.57	6.24	5.45	
	60°	.	11.66	7.12	5.45	5.00	

$12^c = i$

Sonnenhöhe	Lage des Punktes: Höhe über Horizont	Azimut[1]) 0°	45°	90°	135°	180°	Zenit
0°	20°	3.42	.	.	.	0.96	0.06
	30°	1.68	0.65	0.16	0.40	0.70	
	45°	0.53	0.30	0.10	0.22	0.36	
	60°	0.24	0.17	0.08	(0.12)	0.19	
10°	20°	16.02	4.30	1.40	2.36	4.30	0.53
	30°	9.10	2.98	1.01	1.55	2.41	
	45°	3.74	1.89	0.74	0.84	1.33	
	60°	1.80	1.28	0.64	0.59	0.76	
20°	20°	.	6.35	2.58	4.07	6.26	1.26
	30°	14.76	5.08	1.80	2.41	3.50	
	45°	7.58	3.24	1.40	1.40	1.80	
	60°	3.59	2.50	1.27	0.96	1.05	
30°	20°	29.39	8.66	2.95	3.01	5.71	2.09
	30°	.	6.25	2.28	1.68	3.67	
	45°	10.70	5.17	1.86	1.20	1.86	
	60°	5.83	3.97	1.92	1.20	1.20	
40°	20°	25.68	10.65	3.52	3.84	4.39	3.24
	30°	23.96	7.52	3.13	2.46	3.05	
	45°	.	6.97	2.58	1.57	1.72	
	60°	9.24	5.56	2.66	1.64	1.57	
50°	20°	20.00	11.00	4.76	4.13	4.13	4.88
	30°	18.41	9.42	4.23	2.36	2.54	
	45°	.	8.36	3.70	1.92	1.80	
	60°	16.82	7.30	3.91	2.43	2.01	
60°	20°	14.08	11.05	5.91	4.09	3.18	7.46
	30°	16.20	9.84	4.54	2.26	2.27	
	45°	19.37	9.69	4.69	2.54	2.12	
	60°	.	9.84	5.15	3.33	2.88	

[1]) Gerechnet vom Südpunkt des Sonnenvertikals.

Fig. 4. Dorno's Tables 12a, 12b and 12c.